THE

GEOLOGICAL MAGAZINE.

NEW SERIES. DECADE V. VOL. IX.

No. II.—FEBRUARY, 1912.

ORIGINAL ARTICLES.

I.—Some Account of the Geological Work of the late Professor A. E. Törnebohm.[1]

By A. G. Högbom, Professor of Geology in the University of Upsala.

(WITH A PORTRAIT, PLATE III.)

As already mentioned in this Magazine (September, 1911), the Swedish geologist, Professor Alfred Elis Törnebohm, died on April 21, 1911, at the age of 72.

Professor Törnebohm's name is chiefly renowned in the scientific world for an audacious theory in which he postulates an enormous overthrust as governing the tectonics of the Scandinavian mountain range. But his contributions to geological science in other respects are also important enough to give him a distinguished place among his contemporaries. His interest, outside of the geology of the mountain range, was mainly engaged in microscopic petrography and in deciphering the ore-bearing Archæan districts of his country.

Professor Törnebohm was held in general esteem alike for his important scientific works and for his sterling personal qualities. It was, therefore, a great disappointment to his Swedish colleagues that failing health rendered it impossible for him to take a more active part in the geological congress held in Stockholm in 1910.

A short account of Professor Törnebohm's life and a summary of his more important works have been asked for by the Editors of this Magazine, and thus a precious opportunity is afforded to one who, as a younger colleague, has worked in the same fields of research.

A. E. Törnebohm was born in Stockholm on October 16, 1838. In his school and college days he was much interested in chemical and physical experiments; scholarships and fellowships attracted him but slightly. Having in the years 1855–8 passed through the Technical High School of Stockholm, he spent a year in the State Printing Office of Vienna in Austria, there mainly studying galvanoplastic methods of reproduction, allied to the more modern collotype process. His close acquaintance with these methods was of value to him in publishing his geological maps later on.

After his return to Sweden (1859) Törnebohm entered the newly established Geological Survey as State Geologist, and worked there

[1] Professor of Mineralogy at the Technical College, Stockholm, 1878–97, and Director of the Geological Survey of Sweden, 1897–1906. For. Corr. Geol. Soc. Lond., 1910.

until 1873. Several maps (1 : 50,000), with descriptions, were published during these years. Noteworthy among them are the sheets comprising a great part of the Pre-Cambrian complex, generally known as the Dal Formation, which lies west of Lake Wenern. Beneath this Dal Formation, and separated from it by a great unconformity, comes an Archæan complex, the Amal Complex, in which Törnebohm, as far back as 1870, recognized volcanic tuffs and beds of conglomerate; the latter are probably the first described true Archæan conglomerates.

Besides mapping in different parts of Middle Sweden, Törnebohm at this stage of his career entered the highlands and dealt with their stratigraphy in two important memoirs. The first of these memoirs gave a cross section of the mountain range from Ostersund to Levanger (1872), and the second, *Über die Geognosie des Schwedischen Hochgebirges* (1873), was accompanied by a survey map of a considerable part of the highlands. In these papers Törnebohm stated that the fossiliferous Cambrian and Silurian rocks at the eastern border of the mountain range were covered by thick complexes of mica-schists, gneisses, amphibolites, and quartzites. The stratigraphy was regarded as normal and the rock complexes were divided up into a lower series, the Seve Group, and an upper series, the Köli Group, both regarded as younger than the underlying fossiliferous Silurian. Some geologists in Sweden opposed this interpretation, and in Norway the researches of Kjerulf could not be brought into harmony with it. On the other hand, later surveys reaffirmed the general correctness of Törnebohm's observations in regard, that is, to the order of superposition of the strata in the districts examined by himself.

But Törnebohm had no opportunity to pursue his researches in the mountains for some years to come. In 1873 he left his post as State Geologist, and partly for purposes of study, partly for considerations of health, undertook a journey to Italy, Austria, and Germany. He stayed for a time in Leipzig, where, under the guidance of Professor Zirkel, he learned microscopic petrography.

After his return home Törnebohm surveyed several mining districts in Middle Sweden, and in 1878 was appointed Professor of Mineralogy and Geology at the Technical High School of Stockholm; this post, in 1897, he exchanged for the directorship of the Geological Survey.

In the seventies and eighties Törnebohm published a great number of petrographical memoirs, as, for instance, his fundamental *Systematic Research on the Diabases and Gabbros* (1877), and his descriptions of zircon, epidote, scapolite, and calcite as constituents of igneous rocks. He also examined several rock types, new to science, namely, cancrinite-syenite, alnöite, and somewhat later (1907) catapleite-syenite, with associated rocks. His study *Zur Petrographie des Portlandscements* (1905) attracted much attention.

Besides these purely petrographical papers, Törnebohm has left rich material of a similar character in the form of petrographical observations dispersed through his more strictly geological works. For theoretical problems of petrology he had but little interest, and accordingly did not enter much into such matters. The breadth of his researches in petrography is illustrated not only by his writings, but also by his fine

collection of four thousand slides, all made by himself. The grinding and preparation of these slides was for him a daily gymnastic exercise, which he did not like to neglect. It gave him great pleasure to demonstrate to his colleagues new slides showing features of interest.

Petrography was for him, however, more or less an incidental occupation or else a means to an end in his profound researches into Archæan geology. Apart from a series of smaller memoirs dealing with the Archæan, Törnebohm published (1882) his monumental "Map of the Ore-bearing Archæan in Middle Sweden" (*Hellersa Sveriges Bergslag*), on the scale 1 : 250.000. The views set forth by Törnebohm in the text accompanying this map as to the genesis of the Archæan rocks and ores may be, in essential parts, antiquated; but even when regarded from the present standpoint of science, the map promises to maintain its position for a long time as a most important primary source of knowledge in regard to this exceedingly interesting Archæan district. In addition Törnebohm made several ore-fields, included in this same district, as Dannemora, Norberg, Persberg, and Falun, the subjects of more detailed individual treatment, and he also described other mining districts situated elsewhere in the great North European Archæan. Among these may be mentioned the copper-mine district of Atvidaberg-Bersbo, the renowned iron mountain Taberg, south of Lake Vettern, and the Pitkäranta mines in Finland.

Having accomplished the great map of Middle Sweden, Törnebohm resumed his researches in the mountain range. During the ten years that had passed away since he had published his first memoirs about the geology of the highlands, the knowledge of the stratigraphy of the district had but slightly advanced; Törnebohm, however, was fully aware that difficulties met his old interpretation, and that a review of the whole evidence and a correlation of the Swedish and Norwegian parts of the mountain range were necessary. Hardly, however, could he have imagined that he would spend so much as thirteen summers of laborious surveying before he could reach a satisfactory theory of the tectonics!

With admirable perseverance Törnebohm roamed through the barren highlands in all directions, often returning to critical localities, where new suggestions led him to reconsider his old ideas and working hypotheses. It has been told that sometimes his assistants ran away from him because they could not endure the fatigues or follow him when with his great strides he rambled over the mountains. Törnebohm needed but a slight equipment for his personal comfort. Some handfuls of raisins and almonds were often his provisions for a hard working day in the field. The desolateness of the country, want of topographic maps, absence of fossils, sudden change in the facies of the rock-groups, and varying stages in their metamorphism combined to render geological surveying exceedingly difficult. At the present day, thanks to the pioneer work of Törnebohm and to all the added advantages of good topographic maps and developed means of intercourse, students of a younger generation can easily appreciate the main features of the geology, and they can hardly imagine the difficulties which met the first explorations in these mountain ranges.

This is not the place for a detailed account of the development of

highland geology in Sweden; the stages passed through were much the same as in the interpretation of the North-West Highlands of Scotland. It need only be recalled that Törnebohm's first conception of the Seve and Köli Groups as younger than the Silurian could no longer be maintained, since Silurian fossils were discovered in the Köli Schists. In a paper entitled "Om fjellproblemet" ("The Problem of the Highlands"), published 1888, Törnebohm first advanced his hypothesis of a great overthrust: the Pre-Cambrian Seve Group, with the superimposed Köli Schists, he now interpreted as having been thrust eastwards some tens of miles, and in this wise superimposed upon the fossiliferous Cambrian and Silurian areas in the east. The Köli Schists, which have their richest development on the Norwegian side, he regarded as an anomalous facies of the Cambrian and Silurian, differing from the more normal development of these systems, not only through their more or less pronounced metamorphism, but also through their admixture with abundant igneous rocks. Relying upon several discoveries of fossils and on the tectonics, Törnebohm divided up the Köli Schists into a series of subdivisions which may here be passed over. The final result of his extensive researches he published (1896) in the memoir *Grunddragen af det centrala Skandinaviens geologi* (*The Outlines of the Geology of Central Scandinavia*). The memoir is accompanied by a map, on the scale 1 : 800,000, comprising an area of not less than 36,000 square miles.

By travelling in parts of the Scandinavian chain other than those dealt with in the two publications cited above, Törnebohm moreover got a general view of its geology, and was thereby enabled to apply his thrust-theory to the mountain range in its whole extent. This he has done on the maps in his textbooks of geology and on his great wall-map of North Europe.

Several geologists in Sweden, as well as in Norway, are still unconvinced in regard to the great thrusts; none of them, however, has been able to produce a map which can satisfy in any other way the tectonic relations. Admittedly the last word has not yet been said about the mountain tectonics of Scandinavia, but there is every probability that the great lines have been rightly traced by Törnebohm, and that the further development of our knowledge must proceed from the basis laid down by him. The next objects for research will probably be the inner composition and structure of the great thrust-masses, the minor thrusts occurring in them, and the rôle played by the intermixed igneous rocks. Furthermore, the stratigraphy of the great sparagmite complexes needs thorough revision.

Törnebohm's field of research, mountain tectonics and the Archæan, offered a wide scope for subjective views. With the divining rod of his intuitive faculty he often has found the right interpretation where a more wary geologist, considering the lack of information, would have refrained from a definite opinion. His precision of aim was admirable, but he was not safe from great errors. In scientific discussion he was hardly open to conviction. Facts that did not harmonize with his views impressed him but little before he could verify them for himself in the field. In debate he was, therefore, often a fierce adversary, who made his opponents feel the whole

gravity of his authority. But after a strong conflict his soulful eyes again beamed with their usual kindness.

Törnebohm had other interests besides geological, and he was much impressed by spiritualistic and theosophic ideas; in his library literature dealing with these subjects was well represented, but he did not feel inclined to visit spiritualistic conferences or circles; for that he was of too solitary a nature. As a rule he was reticent upon the subject, but some few months before his death he wrote a paper in which he set forth his ideas on transcendental phenomena and vindicated an idealistic standpoint against the materialistic views especially prevalent in popular scientific literature. He expresses here his agreement in these matters with the English physicist F. W. Barret.

Though apparently almost indifferent to popularity and external distinctions, Törnebohm, especially in the last years of his life, much appreciated testimonies of esteem from his Swedish and foreign colleagues. He was, without question, delighted by the honour accorded to him by the Geological Society of London in making him a Corresponding Member (1910).

Having left the directorship of the Geological Survey in 1907, Törnebohm settled in the small idyllic town Strengnäs on the shores of Lake Mälar. Here he retired much from geology. He said that as he had no further opportunity of working in the field or of following the literature he had sense enough to keep silent. Notwithstanding, some small geological papers still appeared. One of his last writings, dating from 1909, describes Pre-Cambrian fossils, found by him in the Dal Formation and in the Norwegian Sparagmite Formation. These fossils have since been identified by Professor Rothpletz in Münich as calcareous algæ.

Sailing, cycling, carpentry, and turnery diverted him towards the end of his life, until the growing infirmities of old age (arteriosclerosis) made an end of such recreations.

Professor Törnebohm was married in 1897, and left a widow but no children.

In Geol. Fören. Förhandl., Stockholm, Bd. xxxiv (1912), a fuller biography of Professor Törnebohm will shortly appear, with a complete list of his published works. Since Professor Törnebohm has written almost all his works in Swedish it may be useful to add that his more important memoirs about the Archæan and the thrust-region have been reviewed and referred to in the author's papers, "Pre-Cambrian Geology of Sweden" (Bull. Geol. Inst. Upsala, vol. x, 1910) and "Studies in the Post-Silurian Thrust-region of Jämtland" (Geol. Fören. Förhandl., Bd. xxxi, 1909), both published in English.

II.—Outlines of Oilfield Geology.

By T. O. Bosworth, B.A., B.Sc., F.G.S.

(*Concluded from the January Number, p. 23.*)

8. *Arenaceous Strata unconformable on an Oil-generating Formation.*—Occasionally a formation, though a parent source of petroleum, does not contain porous rocks suitable for oil accumulation. But a second formation resting unconformably upon the first may be admirably

situated for receiving and storing the oil, for this second formation probably contains the necessary sandstones, and also all the unconformable strata are likely to be more or less arnaceous where they abut against the plane of unconformity, thus facilitating the transfer of the oil from the rocks below (Fig. 9). Cases of this kind occur in California in the Coalinga Oilfield, where oil is obtained from sandstones in the Miocene which lies unconformably over the Eocene; also in Roumania, where the Meotic formation transgresses over the Saliferous.

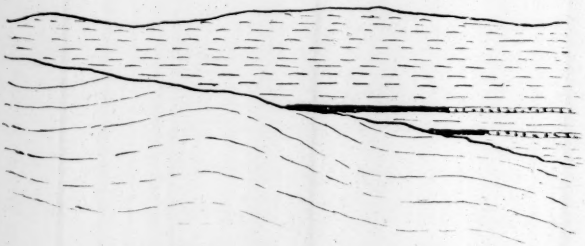


FIG. 9. Oil accumulation in porous strata unconformable on oil-generating strata.

9. *Strata tipping unconformably from an old Shore-line.*—This is supposed to be the case in the Maikop Field, the oil having accumulated in more or less lenticular sands abutting against a shore-line of Cretaceous rocks. Such conditions are favourable to accumulation, for the porous beds are gently inclined and are sealed up at their upper ends (Fig. 10).

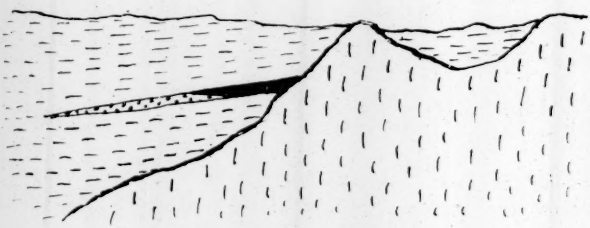


FIG. 10. Oil accumulation in strata tipping unconformably from an old shore-line.

10. *Exceptional Circumstance.*—Occasionally large quantities of oil are obtained from fissures, fault-planes, planes of unconformity, cavities, etc.

B. OIL ACCUMULATIONS DEPENDING ON DENUDATION.—Outcropping petroliferous strata have been referred to by practical men as 'monoclines' in contradistinction to anticlines, which at one time were thought essential for the accumulation of oil. These 'monoclines' are often really limbs of denuded anticlines, and the term would be

applied to several of the cases already described and to all cases where the oil-rocks crop out. Most of the gas and much of the lighter constituents of the oil have generally escaped from outcropping oil-rocks, though under certain circumstances valuable accumulations are found. But oil-sands outcropping far from the anticlinal axis seldom contain much oil.

1. *Oil-sands sealed at Outcrop by Bitumen.*—The escaping oil on evaporation has often left behind oxidized residues which block up the pores of the oil-sand and prevent the escape of the remaining oil.

FIG. 11. Oil in outcropping beds, near anticline, sealed in by bituminous residues.

Large quantities of oil are obtained from such outcropping rocks in many oilfields by drilling to strike them at depth, but the yield per well usually is not great, because owing to the gas having escaped there is but little pressure (Fig. 11).

2. *Oil-sand Sealed at Outcrop by Infiltrated Mineral Matter.*—Surface-waters bearing calcium carbonate or other mineral matter sometimes have deposited cement in the pores of an outcropping sandstone and thus stopped the escape of the oil ascending towards the outcrop.

C. OIL ACCUMULATIONS DETERMINED BY PETROGRAPHICAL CIRCUMSTANCES.—When the rocks are not appreciably folded or denuded the characters of the rocks have been the chief factor in determining the sites of oil-pools.

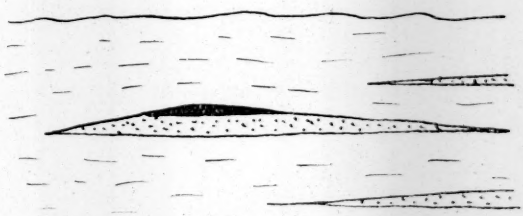


FIG. 12. Oil accumulation in horizontal sand lenticle. Length of section, say 1 mile.

1. *In Lenticles.*—In undisturbed strata big lenticles of sandstone, with impervious clay above, are ideal places for the accumulation of oil (Fig. 12). Being convex they possess much the same advantage as a dome, for the hydrocarbons moving upwards are trapped and concentrated under the apex of the dome-shaped clay roof. Good examples occur in the Oklahoma Oilfields.[1]

[1] "The Origin of Oil and Gas," by L. L. Hutchinson: *Petroleum Review* June 3, 1911.

2. *Discontinuous inclined Porous Beds.*—Where a porous band thins out, becomes fine-grained, or otherwise loses its porosity before reaching outcrop, gas and oil may accumulate at the upper limit (oil at the lower limit if the rock be dry). Examples are known in the Oklahoma and Coalinga Oilfields (Fig. 13), and probably are very common.

3. *Pools resulting from differences in Capillarity and Porosity.*—Over large tracts in the United States where oil is mined from strata situated at great depth and almost undisturbed, e.g. parts of the Appalachian Oilfields, oil is distributed sporadically in isolated pools. The pools are discovered and their limits proved by trial; generally they occur in the most porous parts of highly porous rocks. Probably

FIG. 13. Oil in inclined discontinuous porous beds, as in Coalinga Field. Length of section, say 1 mile.

many of these pools of oil have been driven into their present position[1] by the complicated movements of waters circulating under the guidance of capillary attraction—a force which would vary greatly in different beds, and from place to place in each bed, according to texture, cement, current-bedding, etc.

PART III. SURFACE PHENOMENA OF DECARBONIZATION PROCESS.

The visible indications of this natural process will now be briefly enumerated.

Oil-sands at Outcrop.—At outcrop oil-sands, though they have a pitchy smell, are seldom visibly moist with oil, for on evaporation oxidized residues fill up the pores of the rock. Most common are the oils having an asphaltic base, in which case the bituminous residue is very dark, giving the rock a deep-brown or black appearance. Although an outcropping oil-rock is generally dark and dry, it is often possible with the pick to break far enough into it to find it oily and of a lighter colour. In coast-sections oil-rocks washed by the tides often present this appearance, and sometimes are so soft and sticky that drops of oil may be squeezed out by hand. In strata containing light oil with a paraffin base, however, evaporation may be so complete as to leave little or no indication of petroleum at the outcrop. If, however, the outcropping oil-sands be broken with the hammer, the oil often may be detected by smell, or if water be present, by the oil film which spreads over its surface.

[1] M. J. Munn, "Theories of Gas and Oil Accumulation," *Economic Geology*, 1909, p. 509; also "Anticlinal and Hydraulic Theories", *Petroleum Review*, January, 1910.

Oily Clays.—The exposed clays of a petroliferous formation do not so readily lose their hydrocarbons, and often they are found to smell of oil quite strongly, even where exposed at the surface.

Burnt Clays.—Occasionally, as in Trinidad and California, there occur beds of clay-shale, sometimes 10 feet or more in thickness, which have been naturally burned (at depth) into hard red rock like brick by the combustion of the bituminous material contained in them.

Oil Seepages.—Oil exuding from outcropping oil-sands, or coming up faults and joint-cracks, frequently seeps through the surface soil, forming pools which are sometimes of considerable size.

Likewise films of oil are often seen on the surface of water in swamps, wells, and springs. The surface of the sea is sometimes similarly overspread for miles.

Pitch.—Pitch is one of the commonest indications of oil. Extensive deposits occur in Mexico, California, Venezuela, Trinidad, West Africa, Borneo, Russia, etc. The composition of the pitch depends on that of the oil it is derived from, and also varies according to the extent to which evaporation and oxidation have advanced. Many oil-sands near the surface contain sticky pitch, and spreads of pitch mixed with sand often cover the outcrops and occupy the bottoms of ravines into which they have flowed. Generally the pitch appears on the surface as numerous cones, isolated or in groups. Usually the cones are only a few feet or less in height, but in some places there are pitch hills of 50 feet or more. Single cones are symmetrical, and on the outside may be hard and dry, but at the apex is a little crater from which flow takes place. When cut open it is seen that the cone is built upon the surface soil above some crevice, up which soft sticky pitch and thick heavy oil is slowly ascending through the ground, and thence up the central pipe of the cone to the apex.

In country covered with thick vegetation the outcrops of oil-sands can be traced by the occurrence of pitch and the approximate course of an anticline may be followed for miles. Pitch also occurs at submarine outcrops, for soft fresh pats of pitch are washed up ashore abundantly on the coast of petroliferous country. The extensive deposits of pitch at present on the earth's surface bear witness to the immense quantities of petroleum which have escaped into the atmosphere in recent times.

The best known individual and uninterrupted pitch spread in the world is the Trinidad Pitch Lake with an area of about a quarter of a square mile, but there are more extensive areas covered with pitch in Venezuela. Estimating the total contents of the Pitch Lake at ten million tons, it follows that some forty million tons of oil must have evaporated at that one site alone.

Bitumen in Fissures. — Fault fissures, joint-cracks, and cavities among rocks above or associated with petroliferous strata, are sometimes filled with bitumen derived from the oil. The bitumens derived from asphaltic oils differ from the pitch which is formed from the same oil at the surface, being hard, black, lustrous substances which break with conchoidal fracture. One of the best known of the many different kinds is manjak, which is mined in Trinidad and Barbadoes.

Limestones, sandstones, and conglomerates are often heavily charged with asphaltic bitumen.

The bitumens derived from paraffin oils are soft waxy substances of pale colour, the most important being ozokerite, which is mined in the strata overlying the oil rocks at Boryslav in the Galician Oilfield, and also occurs in quantity on the island of Cheleken. This ozokerite occurs in fissures sometimes as lumps and cakes weighing several pounds, but the main production is obtained on treating the clay shales with hot water.

Gas.—Exudations of gas are numerous in most oilfields, ascending through the surface soil from outcrops and fractures. Generally they can be detected by the smell, and often also they can be ignited and may burn continuously. In wet ground the noise of the gas bubbling up through pools of water assists detection. Occasionally violent outbursts have been known to blow out cavities in the rocks.

Sulphur.—Sulphuretted hydrogen and sulphur-dioxide frequently accompany the escaping gas, and deposits of sulphur in cracks in the rocks or on the surface are not uncommon indications of hydrocarbons below.

Sandstones in Peru, and thick limestones in Texas and Louisiana, are impregnated with sulphur to such an extent that when they are heated melted sulphur runs out. Hot sulphurous springs of water are of frequent occurrence in oil territory, and often when a well approaches exhaustion sulphur water ascends.

Salt.—The complete relationship between salt and petroleum is not understood, but it is a conspicuous fact that salt is nearly always in some way associated with petroleum either as crystalline masses of rock-salt, or salt water, or saliferous strata. It is true that the conditions favourable for the preservation and storage of hydrocarbons are also those favourable for the presence of bodies of imprisoned sedimentation water, but the salt water which accompanies petroleum is usually much more saline than the water normally present at depth in sedimentary rocks, and suggests some further relationship.

Mud Volcanoes.—These occur in almost all parts of the world where oil-rocks approach the surface. They are built up over springs which exude mud, gas, and hot water often with a little oil. Sometimes mud volcanoes form hills a hundred feet or even several hundred feet high, but most numerous are small cones rising only a few feet. Common also where much water accompanies the mud are volcanoes of larger area and very slight elevation. A typical example observed by the writer in Trinidad had a soft mud crater of 35 yards diameter, in the middle of which was a salt pool 12 yards across.

The noise of the great gas bubbles, which burst up every minute or two, could be heard two or three hundred yards away. The soft mud was surrounded by harder mud on which one might cautiously walk, the whole volcano forming a nearly flat, bare mud patch of 100 yards diameter, in the midst of thick forest. The volcano was surrounded by a little moat into which streams flowed from the crater. Outside this, sandy ground rose 5 or 10 feet, but was cut through in one place by a miniature gorge where the muddy salt water found egress from the moat as the source of a stream.

Sometimes mud volcanoes act with such violence as to throw up tons of clay and rock 20 or 30 feet into the air, and in two known instances small islands, hundreds of feet across, have been built up off the coast by submarine mud volcanoes situated on well-known anticlines.[1] Mud volcanoes occur chiefly along the crests of anticlines or along fault lines.

Conclusion.

Petroleum or other bituminous matter is common in small quantity in sedimentary rocks of all ages, and in certain cases where the structure is favourable it is present in large amounts.

Some idea of the quantities of oil found imprisoned in the earth's crust is obtained from a study of oilfields' statistics. The world's annual output during the last few years has exceeded 40 million tons, whilst from only 6 square miles of country near Bāku 11 million tons of oil were extracted in one year, and it is estimated that the oil which has been obtained from one 27 acre property there would fill a tank of that area to a depth of 270 feet.[2] In a number of instances in various parts of the world the amount of oil yielded in one year by a single well has exceeded 100,000 tons. At the present time immense quantities of petroleum oil and gas are escaping naturally at the earth's surface almost wherever Tertiary strata have been upraised and exposed to denudation. This is a natural process of decarbonization; shallow-water sediments, which probably have formed the main bulk of the marine deposits of every age originally contain a great amount of carbonaceous material disseminated in their muds, and this carbon is capable of undergoing chemical change into volatile hydrocarbons, which must be eliminated ere the composition of the rocks is stable.

Thus we do not now commonly find oil in the older rocks, except where they have been deeply buried and sealed up by newer formations practically undisturbed. Under such circumstances occur vast stores of oil in the Silurian, Ordovician, Devonian, and Carboniferous formations in the Appalachian fields of the United States. But in the majority of oilfields the oil-rocks are of Tertiary age.

The decarbonization of the freshly upraised Tertiary sediments is taking place in the earliest stage of their denudation, and long ere the next marine transgression has overlaid the area with new permanent deposits, it is likely that further denudation will have entirely obliterated all records of the process, leaving in the Tertiary as little indication of petroleum as in the old formations now. It is therefore not improbable that the older formations were as petroliferous as the Tertiary, and that the decarbonization process at present witnessed on the surface of the newly upraised sediments has been usual on similar occasions in the past; or, in other words, many of the old planes of discordance have been the scenes of phenomena similar to those described above.

[1] A. Beeby Thompson, *Petroleum Mining*, 1910, pp. 102, 103.
[2] Ibid., p. 86.

III.—The Tachylite of the Cleveland Dyke.

By Miss M. K. Heslop, M.Sc., and R. C. Burton, B.Sc., F.G.S.

(PLATE IV.)

THE Cleveland Dyke is well exposed low down on the left bank of the River Tees, near the junction of this river and the Lune, being washed at flood-times by the water. It trends in a direction north of west, and can be traced for a distance of several hundred yards: its thickness is difficult to estimate as the north edge is covered by drift. The tachylite variety of the rock is only exposed for a few yards, and has only been found at this point—about 100 yards west of the junction of the Lune and Tees. The dyke here appears to occur in sheets very like successive lava-flows, and during cooling a columnar structure has been developed and the bases of the columns, mostly hexagons, face the river. The Cleveland Dyke at this exposure is represented by three varieties of rock—

1. Ordinary porphyritic rock.
2. Amygdaloidal porphyritic rock.
3. Stony rock associated with tachylite.

It is with the third variety that this paper is concerned. The stony rock occurs as a layer 1½ feet thick, dipping 10° E.S.E. at a point just opposite the junction of the two rivers, while a few feet higher up the Tees the dip changes to 10° W.N.W.; above and underneath it the ordinary variety of the dyke occurs, and the junctions are quite as sharp as between successive lava-flows.

The true tachylite occurs as a selvedge ½–¼ inch thick, covering the stony rock on its southern face for a distance of several yards, and also seems to occur as veins in this variety. The latter mode of occurrence is remarkable, and suggests that just before consolidation part of the magma on the extreme edge of the dyke was injected into cracks in the very viscous layer adjacent to it, the temperature of which was low enough not to interfere with the almost immediate consolidation of the injected material as tachylite. This explanation, however, is put forward with a considerable amount of hesitation. In some parts of the exposure the stony rock forms an inner selvedge about 4 inches thick, while the tachylite covers this as a thin outer selvedge.

A few yards higher up the river there is an overflow of the dyke to the south. A black shale is found lying horizontally underneath the dyke for a distance of 11 yards; we could not determine whether the shale was greatly baked or not as the river water has softened the rock and altered it; the junction of the shale and the dyke is also difficult of access. This fragmentary section is, however, sufficient to point to the existence of a small overflow to the south, and this conclusion is supported by the occurrence of the igneous rock in sheet-like form, where the tachylite is found; lower down the river the ordinary dyke-form is resumed. The actual extent of the overflow, as seen, is 11 yards, but it is probably exposed over a greater distance. Its existence is interesting as it seems to prove that, for some reason possibly connected with the hade of the dyke, the injection of the molten magma has taken place with particular force to the south;

other overflows are known at Bolam and Buckheads, near Bishop Auckland, and have both taken place pre-eminently to the south.

As seen in the hand-specimens the tachylite is a hard black rock with a vitreous lustre, weathering to greyish on the surface. This colour change due to weathering is also well shown under the microscope, the tachylite becoming lighter near the devitrification cracks. The glass was infusible in the Bunsen flames, but with the blowpipe a black globule was formed, the fusibility lying between two and three on the scale. The specific gravity from several determinations is 2·60, while that of the ordinary variety of the Cleveland Dyke lies between 2·63 and 2·788.[1] The hardness was found to be 5·5. On treating some of the substance with hydrochloric acid to get rid of superficial iron-oxide, it was partly bleached on the surface to a greyish colour; this was thought to point to the existence of free magnetite, but the tachylite proved to be non-magnetic, being absolutely without effect on even the most sensitive mirror-galvanometer. Some of the tachylite, when treated with acid, seems to be heterogeneous, part being jet-black and part greyish-yellow; the latter probably due to a slight devitrification and decomposition with formation of chlorite.

The black variety was carefully sorted out and used for analysis. The methods used were those described by Hillebrand in Bulletin No. 422, Geological Survey, U.S.A. The results are recorded below, together with the analyses of the ordinary variety of the dyke, of the glassy groundmass as determined by Stock, and of the tachylite from the Western Isles of Scotland.[2]

	Tachylite of the Cleveland Dyke.	Normal variety of the Cleveland Dyke.	Glassy base of groundmass of Cleveland Dyke.	A tachylite from the Western Isles of Scotland.
H_2O	1·55	1·55	—	3·50
CO_2	3·64	3·60		
SiO_2	55·19	56·10	70·76	56·05
MnO	0·63	—	—	traces
CaO	7·53	11·20	3·29	6·66
MgO	4·12	2·29	4·21	1·52
Fe_2O_3	10·23	4·76	3·59	10·30
Al_2O_3	12·30	17·24	10·93	17·13
TiO_2	1·03	—	—	—
Na_2O	2·13	2·04	7·22	3·29
K_2O	1·30	1·38		0·98
	99·65	100·16	100·00	99·43

The composition of the tachylite is seen to correspond closely with that of the ordinary variety of the dyke—the similarity is yet more noticeable if other analyses of the dyke are considered. The particular analysis given was chosen because its percentages of water and carbon dioxide are the same as those in the tachylite. The silica percentage

[1] J. J. H. Teall, "On the North of England Dykes": Q.J.G.S., vol. xl.
[2] Judd & Cole, Q.J.G.S., vol. xxxix.

in the glassy rock is slightly lower—further analyses would probably give a slightly higher figure; the sum of the lime and magnesia is somewhat lower, while the sum of the oxides of iron, aluminium, and titanium is higher than in the ordinary variety of the dykes, and the alkalies are practically identical.

These results, then, agree with the evidence as to the identity of composition of the tachylite and ordinary variety of a dyke obtained by Judd and Cole from a study of the dykes of the Western Isles of Scotland, which we will now briefly refer to.

We know of but one more example of a glassy rock of this kind from the North of England dykes,[1] so that it will be interesting to compare the Teesdale tachylite with that from the Western Isles of Scotland. The dykes differ fundamentally in the presence of olivine in the Scottish rocks and its absence from the Cleveland Dyke—at all events, at this exposure the latter is an augite-andesite, while the former are described as olivine basalts; the non-magnetic character of the Teesdale tachylite also distinguishes it, and it seems probable that the oxide of iron exists in a different form in this rock, as ferric oxide, or at least not combined to form magnetite as seems to be the case in the Scottish variety. The latter is also an exception to the rule that the specific gravity of the tachylite is less than that of the ordinary variety of a dyke; we have already seen that the tachylite of the Cleveland Dyke conforms to this rule. It is interesting to note that both the glassy rocks contain corroded augites and felspars, showing that the conditions of intrusion of the two magmas must have been similar. In chemical composition there is a great resemblance between the two rocks.

When examined under the microscope the slides show a glassy rock passing abruptly into a larger mass of true tachylite about $\frac{1}{8}$ inch in thickness at the outer margin; the sections fall naturally into the following divisions (see Pl. IV, Figs. 1, 2):—

I. Tachylite { (*a*) Pale pinkish-brown layer.
(*b*) Bright yellow layer in contact with (*a*).

II. Stony rock { (*a*) Dark granular region of irregular limits merging into
(*b*) Light-grey area in which swirling black streams still mark the 'lines of flow'.

Flow-structure, indeed, is evident in both the main divisions of the section: in the tachylite the lines run parallel to the junction; in the stony layers beneath they curve and twist about much more, at a little distance below the actual contact, but with a general trend in its direction.

The Tachylite (Plate IV).—The spherulitic nature of the tachylite is quite plain in ordinary light, for the presence of chlorite in the interstices serves greatly to emphasize the outlines of the spherules. The yellow band, Fig. 1 (Ib) differs in no important point from the upper tachylite,

[1] A slide of this rock in the collection of Dr. Teall was examined, with his kind permission, by Miss Heslop; it is marked "Tachylite, 3½ miles east of Greenhaugh", and contains well-formed porphyritic augites (with large optic angle) not unlike those of the Cleveland Dyke, but they are pierced by ground-mass felspars.

and its colour—the only distinction—is certainly the result of contact with the highly ferruginous dark rock below it. A somewhat different character was shown by a fresher specimen of the chilled margin (Pl. IV, Fig. 2) from which a section was cut, more or less parallel to the contact surface of tachylite and 'stony rock'. The fresh glass in this instance was brown, isotropic, and apparently quite amorphous (BG, Fig. 2), for, though it was suggestively granular, no actual grains could be focussed. Light-yellowish bands (C, C) of varying thickness (0·08–0·09 mm.) cross the dark glass in all directions, dividing it up into somewhat angular areas, which show faint but distinct zones of colour (Z, Fig. 2), pale on the outside but grading down to the normal dark brown at the centre of each patch. The light-yellow bands (C, C) consist of distinct fibres (ch, Fig. 2), which lie at right angles to a central crack. In every case a crack seems to have been the starting-point for the devitrification process. There can be little doubt that the cracks themselves are due to cooling.

Lines of flow such as are seen in the layers beneath the tachylite or even in transverse sections of the tachylite itself do not occur here, but certain proof of flow-movement is available in the drawn out and distorted bubbles, which are quite common (see b, b, Fig. 2). Some of them are black and opaque and seem to have an internal cavity, but there are others (X) which present rather the appearance of a highly refracting material of golden brown colour, not unlike rutile. They are brilliantly polarizing, but clearly owe their interference colours to small pleochroic laths felted together, which must either form the walls or be the decomposition product of some substance now filling the gas cavities. There can be no doubt, from their parallelism and general likeness, that the black-lined cavities and the yellow highly polarizing areas are of similar origin, but that a deposit of iron-oxide has produced the dark colour in one case, while devitrification is responsible for the pleochroism and double refraction in the other. The local concentration of iron-oxide here finds a parallel in the lower layers, where alternating dark and light 'streams' indicate the local abundance and scarcity of granular iron-oxide.

Porphyritic felspars and augites, besides small varieties of both these minerals, occur plentifully in the tachylite. All the crystals are faulted by the cooling cracks when they lie in their paths, and, more than once, small augites were seen apparently dividing the distorted bubbles, thus showing that they were formed prior to the movement which drew out the bubbles into their present elongated shape. There is a perfectly sharp line of division between the tachylite and the adjacent rock, and although practically the same crystals exist on both sides of this line, the bases in which they are embedded are quite distinct.

The Stony Rock.—This consists mainly of masses of yellowish-green fibres, among which lie small specks of iron-oxide; these accumulate in greater numbers and attain a much greater size in the dark area and in the dark bands, whose meanderings indicate the flow-lines at this part. It is to the iron-oxide specks that the granular appearance of the 'stony rock' is due, and an increase in their size and number is apparently accountable for the darker regions of the base here.

In the less disturbed places, where flow-structure is not greatly in evidence, the fibres sometimes attain the size of ordinary skeleton augites, which they resemble in general mode of occurrence. Individual needles sink to the minutest dimensions, however, in the disturbed parts and lose their parallel disposition, becoming more felted together without definite plan or arrangement. These differences may be taken as indications of the stages of incipient crystallization produced under the two circumstances; in neither is it far advanced, but those parts which solidified with moderate quiescence allowed more opportunity for the development of the skeleton growths, whose decomposed form, supplemented by further devitrification, we now see in the parallel bundles of green needles. There is therefore no structural affinity between the base of the tachylite and that of the adjacent 'stony rock'.

Crystals are sparsely but uniformly distributed throughout the slides, and are as abundant in the tachylite as in the 'stony rock'. The *porphyritic felspars* seem to belong chiefly to the andesine variety, but they approach labradorite in the central parts of the crystals and pass into a more alkaline type in the outermost zones. Many of the smaller laths must also be classed with andesine, and while some are undoubtedly labradorite there is, on the other hand, a transition towards oligoclase. On the whole, however, there is little range of composition; the majority belong to andesine, and exceptions in either direction are rare. Those porphyritic crystals and groups which are found in the tachylite are not much altered, but some of the porphyritic individuals of the 'stony rock' are often greatly decomposed, faulted by cooling cracks, and crushed, while others seem to have been overwhelmed by the 'lines of flow'. The smaller laths, binary twins for the most part, are quite frequently bent or even broken, especially in the tachylite.

The *large augites* have suffered more severely from magmatic corrosion than the felspars. Some crystals are curved, some are invaded by masses of glassy base, while all alike are characterized by rounded angles. They seem to be typically rather broad octagonal prisms of pale yellowish-brown colour, and are distinctly pleochroic. The largest crystals were too much deformed to permit of a thorough optical examination, but two smaller ones showed practically uniaxial interference figures, which is in agreement with the character of the older augites of the Clevéland Dyke.

Small augites are by far the most abundant crystalline constituent of the rock at this part. They occur in small beautifully sharp-edged octagonal prisms, which are generally grouped together but rarely intergrown. They are not noticeably pleochroic. There is none of that bleaching of the groundmass in their neighbourhood, which is frequently found in the vicinity of small ferro-magnesian minerals embedded in a dark glassy matrix. The extinction angle on the $B(010)$ face is from 35° to 40°.

There are small groups of felspar often stellate in arrangement, bound together by a central cluster of granular augite (Plate IV, AF in Figs. 1 and 2). An apparent development of this on a larger scale shows a central patch consisting entirely of granular augite—often

resembling a spherulite in the radial arrangement of its small crystals—which is outlined as a rule by tangentially disposed felspar laths. There are several such patches both in the tachylite and in the 'stony rock', but they are more numerous in the latter. In all cases, however, the patches in this contact variety of the Cleveland Dyke are much smaller, both in general outline and in the internal development of their crystalline constituents, than similar structures occurring in the interior of the intrusion (e.g. in the centre of the Bolam laccolite), so that the suggestion which has more than once been put forward to account for them—that they are a lateral fine-grained variety of the typical rock, which has been broken up and floated away by later re-heating—receives a distinct check (though not actual disproof) by their scarcity at the margins and their abundance and large development in the central portions of the intrusion. Moreover—and it has been observed and mentioned elsewhere [1]—these groups are absolutely holocrystalline (which is unusual in marginal solidifications), and they always consist of an internal granular mass of augite with a few grains of iron-oxide and an external border of felspar laths.

This paper deals principally with the contact variety, but it would be incomplete without some reference to the typical rock. The general structure and mineralogical composition of the Cleveland Dyke are too well known to need more than the briefest description here. The dyke is classed by Dr. Teall in his *British Petrography* as an augite-andesite, "porphyritic in texture, the porphyritic character being determined by the presence of tabular crystals of labradorite . . . still recognizable at chilled margins." In the specimens of the typical rock which were examined the felspars were indeed similar to those in the tachylite, but were much more numerous. The majority, however, including the porphyritic individuals, must still be referred to andesine rather than to labradorite, though examples of the latter variety do occur. There is a greater range towards the alkaline end of the felspar series here than in the tachylite. Several felspars with the mean refractive index of oligoclase were seen, and some sank to that of albite. These were large well-formed crystals, but, in the case of the albite, of somewhat ill-defined outlines. The typical augites of the Cleveland Dyke will, it is hoped, be fully described in a subsequent paper; it is sufficient at present to say that they are identical with those of the tachylite. Iron-oxide occurs in no great abundance, and even in the central parts of the intrusion it exists in small incomplete or skeleton forms, so that its granular nature at the margin is in no way remarkable.

The marginal type of groundmass is described by Dr. Teall as

[1] "On the Crookdene and Related Dykes," by Miss M. K. Heslop, M.Sc., and Dr. J. A. Smythe, Q.J.G.S., February, 1910. The suggested explanation of the micro-crystalline groups given in this paper has received support from subsequent observations, and especially from the case under discussion. Dr. Teall very kindly lent me some slides of the North of England dykes, and one was found to satisfy almost perfectly the requirements of a semi-vitreous marginal solidification, which had been broken up into more or less angular fragments by a later re-heating. In this case the fragments consisted of devitrified glass, in which were embedded various elementary crystals, while they (the fragments) were embedded in a similar devitrified glass with some quartz.—M. K. H.

a "veritable mikrolithen filz, a closely-matted aggregate of minute felspar microliths", and this is, in general, the character at the borders of the Bolam and Cockfield laccolites; it is in strong contrast to the almost homogeneous glass with its small supply of felspars, which is discussed in this paper. It is true that a little earlier in the same paragraph as the above quotation we find that "in one instance only was an isotropic glass observed, and then the glass was seen to contain longulites and globulites similar to those in the Eskdale Dyke". This cannot be said of the Teesdale tachylite, for although it contains crystals they have, even the smallest (which are seen penetrating bubbles) been formed before they reached their present position, where there is no evidence of crystallization having proceeded; for the glass, where undevitrified, is absolutely homogeneous, so far as can be determined by present microscopic appliances.

It will be convenient here to discuss a few points concerning the petrology, and the relations between the tachylite and the glass of the groundmass of the dyke. Some very interesting conclusions may be drawn from the observations on the connexion between the cooling cracks and the crystals of the tachylite. It has been pointed out that two generations of crystals occur—

1. The porphyritic felspars and augites.

2. The groundmass felspars and augites, few and small, and it has been shown that all these crystals were formed prior to the tachylite itself, which was undoubtedly produced in situ by rapid cooling at the edge of the dyke. The history of the magma is, therefore, as follows.

The porphyritic crystals were formed first, and were floated up by the magma from a fairly low depth, when it was intruded into the fissure; but on the way cooling began, possibly during periods of quiescence, and new crystals of a later generation were formed, and probably the zoning of the felspars commenced. The residual magma was rapidly cooled where it came into contact with the walls of the fissure, and the tachylite was formed; this glass, then, we may term the 'primary groundmass', enveloping crystals of two generations, the later generation being one of extended duration. But in the centre of the dyke crystallization proceeded, yielding the groundmass crystals and continuing the zoning of the felspars; finally, we had left the 'later groundmass', which according to Stock's analysis is of acidic composition. One glass is thus, in a way, formed from the other, and the groundmass of the dyke is a product of differentiation by crystallization from a material having the same composition as the tachylite, which is an intermediate rock. Moreover, the glass of the groundmass analysed by Stock is much richer in alkalies than the tachylite or the ordinary variety of the dyke, so that it is not surprising to find that the outer zones of the porphyritic felspars are of a more alkaline type than the inner zones; and even whole crystals of albite occur. Thus, as differentiation by crystallization proceeded we had felspar material of a more alkaline type crystallizing out, and it is evident that the albite crystals were the last formed; and from their ill-defined outlines it is inferred that they had not time to fully develop.

This supplies us with a good example of the power of differentiation by crystallization, and it seems probable that if pressure had supervened, so as to strain off the crystals of the 'later groundmass' and squeeze out the latter, an acidic rock would have resulted. Although this possibility was not realized in this case it has been an important factor controlling differentiation in other instances.

General Review and Conclusions.

We find a 'stony rock', consisting of a base in which there is evidence of incipient crystallization, passing quite abruptly into a layer of tachylite ($\frac{1}{4}$ to $\frac{1}{8}$ inch) in thickness. The 'stony rock' is granular in appearance owing to the presence of minute specks of iron-oxide. These increase markedly in size and number in the rock adjacent to the tachylite, giving rise to the 'dark area'. Dark streaks of a similar nature mark the lines of flow in the paler rock (Pl. IV, Fig. 1).

The spherulitic devitrification of the tachylite in contact with the adjacent layers may be evidence of a not perfectly homogeneous condition at the time of solidification, but the outer part of the glass is certainly homogeneous, for there the devitrification is clearly guided by the cooling cracks along which it started.

There are crystals—porphyritic and smaller individuals—in both parts of the slides, but they are much more altered, faulted, and deformed in the 'stony rock'. Some curved felspar laths in the tachylite show that the temperature there had approached that of their melting-point. Small masses of granular augite associated with felspar laths, either in stellate groups or tangentially disposed to form a border, occur here as well as in other parts of the intrusion. They have been found in every section from all localities, but they are certainly largest and most numerous in the central parts of the dyke. That they are smaller and rarer here is distinctly opposed to the idea that they are a fine-grained lateral consolidation, which has been broken up by a later melting of the rock, while there is nothing to disprove the suggestion of a local eutectic mixture produced by the progressive abstraction of material in a small area walled off by the crystals (felspars usually), which by withdrawing materials for their own growth give rise, instantaneously perhaps, to the conditions necessary for the spontaneous crystallization of the remainder.

The distribution of the cracks is interesting. In the outer part of the tachylite they are ubiquitous; then they become scarce and never extend into the adjacent 'stony rock'. In this latter one set of cracks runs at right-angles to the junction, but no crack passes into the tachylite. Another set, more or less parallel to the junction of the two types of rock, bounds the very irregular limits of the 'dark' rock, while a third set converges towards the second at a large angle and does not as a rule pass it.

The dark area seems to bear the same relation to the adjacent rock that the tachylite bears to it; in other words, it would seem that the tachylite cooled first, forming a rather firm viscous film, past which the still molten magma continued to flow. Evidence of this is found in the appearance of one or two large felspars, which suggest having

been rammed up against the tachylite layer and even forced a little way into it, breaking during the process. Evidence, too, of the viscosity of the tachylite is found in one of its felspar laths which curve with the curve of the junction line between the tachylite and stony rock.

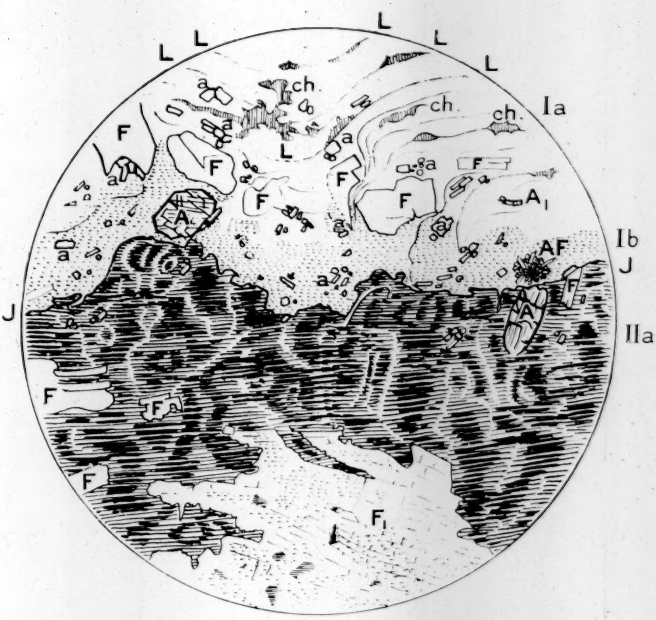
The dark area probably cooled next and adhered to the firm surface of the tachylite, while movement, either of flow or more probably of contraction and contortion due to cooling and settling down of the great mass of the dyke, continued in the adjacent regions. For this reason portions of the dark layer are torn down and tongues of paler rock are forced right up to the tachylite. There can be little doubt that the rapid formation of the film of tachylite retarded the cooling of the adjacent magma, and thus the marked difference between the glass and stony rock is accounted for, while their perfect contact is due to the adherence of the continually cooling material to the only firm surface in the vicinity, that of the tachylite, contact with which further accelerated cooling. There would thus be a continually increasing number of layers of viscous rock bound together more closely than to the adjacent mobile material. Comparison with a typical section of the Cleveland Dyke (from Cockfield) shows that the porphyritic felspars have the same appearance and composition, but while most of the smaller laths belong to andesine with a little labradorite there is a noticeable development of more alkaline species in the Cockfield specimen but not in the tachylite. This is readily understood: the alkaline felspars are among the later crystallizations, which were entirely checked in the tachylite. The large augites are the same in both cases. The small augites of the typical rock are about twice or three times as large as the corresponding crystals in the tachylite, and while the former often have a surface coating of black grains of iron-oxide, the latter are absolutely free from them. Iron-oxide, indeed, does not occur as a primary crystalline constituent in the tachylite. Comparison with other contacts, as well as with the typical rock, shows that a marked suppression of the smaller felspars must have taken place in the tachylite, while an impetus was apparently given to the formation of small augites. This indicates a local inversion of the usual order of crystallization, which generally places felspar before augite in each generation in the Cleveland and many other dykes.

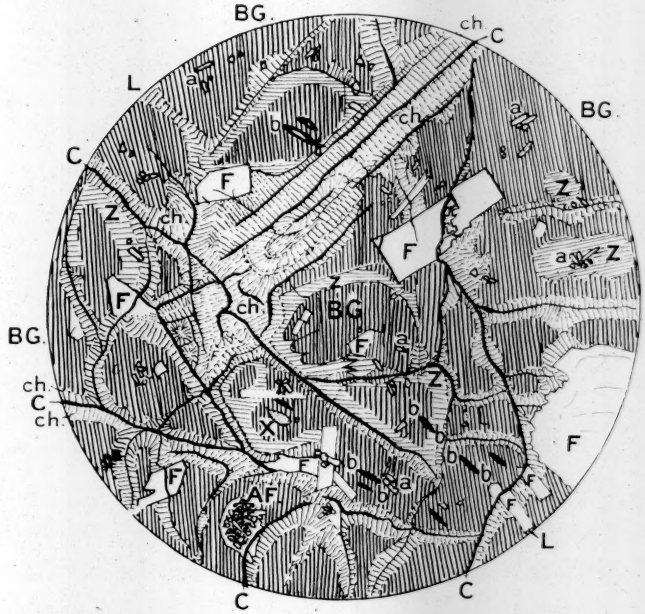
EXPLANATION OF PLATE IV.

FIG. 1. Junction of Tachylite and 'Stony Rock', Cleveland Dyke.

Ia. Tachylite, pinkish-brown layer.
Ib. Bright-yellow (stained) band in tachylite.
IIa. Dark layer of stony rock.
L, L. Lines of flow, only shown here in tachylite, but very clear in the stony rock.
F. Felspars. F_1, large, deformed, and partly decomposed individual.
A. Large augites. A_1 is a small prism, faulted and drawn up by a 'flow' line.
a. Small augites usually in groups.
ch. Areas occupied by green chlorite. Their shape is determined by the spherulites (only seen with crossed nicols) in the tachylite.
AF is a group of felspars with a central cluster of granular augite.

FIG. 1.





M. K. Heslop del.

FIG. 2.

Tachylite, Cleveland Dyke.

J, J. The line of junction between tachylite and stony rock is perfectly sharp. It is seen apparently truncating a small felspar on the right-hand side, while a curved lath is seen just below the contact near the centre of the figure. The cracks in the lower layers are not well shown.

FIG. 2. Shows a section cut roughly perpendicular to the upper part of Fig. 1.

C, C. Cooling cracks. ch. The chlorite fibres bordering them. BG. Dark-brown isotropic glass. Z. Zones of paler glass. F. Felspars often faulted by cooling cracks. The direction of flow (L, L) is shown by the shape and parallelism of the black cigar-shaped bubbles (b, b); some of these are apparently hollow, while a yellow variety is shown at X. It is quite evident that the cooling cracks here (C, C) have no connexion with the direction of flow; indeed, they are sometimes seen faulting the bubbles.

IV.—The Late Palæozoic Alkaline Igneous Rocks of the West of Scotland.

By G. W. Tyrrell, A.R.C.Sc., F.G.S., Assistant to the Professor of Geology, Glasgow University.

Introduction.

Of late years it has become manifest that the igneous rocks of the Carboniferous in Central Scotland have a distinct alkaline facies. Such rocks as monchiquite, nepheline-basalt, mugearite, kulaite, phonolite, essexite, and teschenite have been described from the Lothians; whilst in the western counties nepheline-phonolite, theralite, mugearite, and teschenite are already known. There is abundant evidence, however, that in the West the alkaline phase is of later date than in the Lothians, and of late Carboniferous or Permian age. In Arran it probably extended into the Triassic, assuming that the stratigraphy which assigns certain rocks to the Triassic is correct. A general account of this connected suite of alkaline rocks, together with the lavas in the Mauchline Basin, to which they can be shown to be genetically related, is given in this paper, which deals only with rocks demonstrably later than the volcanics of the Calciferous Sandstone. The work on which this paper is based was commenced in 1908, and was assisted in 1909 by a grant from the Government Grant Committee of the Royal Society, for which grateful acknowledgment is made. An unfortunate breakdown in health, however, necessitated the postponement of the investigation for nearly a year. It is still incomplete owing to the difficulty of obtaining adequate chemical analyses, without which it is impossible accurately to determine the affinities of some of the rocks. Pending the completion of the detailed work it has been thought advisable to present this preliminary account of an igneous suite of extraordinary variety and interest.

Literature.

A brief account of the literature has been given in an earlier paper.[1] Allport described some of the rocks in his classic paper on "The Carboniferous Dolerites".[2] Teall first recognized the teschenitic

[1] Trans. Glasgow Geol. Soc., vol. xiii, pt. iii, p. 300, 1909.
[2] Q.J.G.S., vol. xxx, pp. 529–67, 1874.

affinities of the intrusion of Necropolis Hill, Glasgow.[1] Many details of geological occurrence and petrography are to be found in Sir A. Geikie's *Ancient Volcanoes of Great Britain*.[2] Numerous notes have been contributed by the Geological Survey during recent years. Analyses of the Barshaw theralite and the Lennoxtown essexite have been made;[3] whilst the occurrence of nepheline in some of these rocks was recorded by Bailey in 1909.[4] The teschenites of the vicinity of Glasgow have been described by Macnair,[5] and the teschenite-picrite sill of Lugar by Boyle.[6] A classification of the Post-Carboniferous igneous intrusive rocks of the West of Scotland was given by the writer in 1909, but that classification must now be amended and supplemented in many particulars.[7]

Petrography.

A brief systematic description of the main types of intrusive rocks and of the Mauchline lavas is here given. Much mineralogical detail of great interest and importance and also the detail of field geology is necessarily omitted or greatly curtailed, but will be given at length in the detailed papers which it is hoped will soon be published.

The intrusive rocks may be classified broadly into three groups—

A. Rocks with conspicuous analcite.
B. Rocks with conspicuous nepheline.
C. Rocks without conspicuous analcite or nepheline, but which may contain either or both as accessory constituents.

A. *Rocks with conspicuous Analcite.*

These may be subdivided into five groups as follows:—

1. Analcite-syenite, in which an alkali-felspar is predominant.
2. Teschenite, in which a lime-soda felspar is predominant.
3. Picrite-teschenite, an ultra-basic differentiation facies of teschenite.
4. Lugarite, a leucocratic rock with affinities to ijolite.
5. Monchiquite, a lamprophyric sub-group.

Of these the teschenites are by far the most abundant.

1. *Analcite-syenite*.[8]—This exceedingly rare rock-type is found in a remarkably fresh and perfect occurrence at Howford Bridge, near Mauchline, Ayrshire. It is exposed in the cliffs of the River Ayr, and forms a lenticular intrusion into the lavas and tuffs which underlie the 'Permian' red sandstones of the district. In hand-specimens the rock is medium to fine grained and whitish in colour. It consists mainly of well-shaped felspars with a general parallel arrangement giving a trachytoid aspect to the rock. The long acute-angled interspaces are filled with greenish analcite and dark ferromagnesian minerals. The most prominent constituents,

[1] *British Petrography*, 1888, p. 194.
[2] Vol. ii, pp. 58–67, 1897.
[3] *Summary of Progress of Geological Survey for 1907*, 1908, p. 55.
[4] Ibid. for 1908, 1909, p. 44.
[5] Trans. Glasgow Geol. Soc., vol. xiii, pt. i, pp. 56–86, 1907.
[6] Ibid., vol. xiii, pt. ii, pp. 202–23, 1908.
[7] Ibid., vol. xiii, pt. iii, pp. 298–317, 1909.
[8] *Nature*, vol. lxxxii, p. 188, 1909.

however, are large black, lustrous crystals, the lustre of which is interrupted by metallic patches which themselves become lustrous when the rock is held in a different position to the light. These lustre-mottled aggregates are composed of titanaugite[1] and ilmenite, and occur in increasing abundance towards the base of the sill. In an acid variety of the rock which occurs in contemporaneous stratiform bands and veins ranging up to 2 feet in thickness these augite-ilmenite aggregates are absent.

In thin section the rock is found to be composed principally of alkaline felspars (anorthoclase, orthoclase, albite) and very subordinate labradorite, with abundant interstitial analcite of perfect freshness and limpidity. The felspars and analcite make up the great mass of the rock. The ferro-magnesian constituents include titanaugite, ægirine, brown and blue soda-amphiboles, ilmenite, and occasionally a very little olivine. The texture is medium-grained, and the fabric equigranular to trachytoid.

In the analcite-syenite proper anorthoclase is the dominant felspar. It occurs in well-shaped square or rhomboid sections frequently showing the minute microcline twinning characteristic of this mineral. It is usually bordered by a broad zone of orthoclase. Albite occurs as occasional perthitic intergrowths, as independent idiomorphic crystals, and as a product of the 'albitization' of the labradorite. It is nevertheless not abundant. In the more basic types labradorite forms broad zonally-built crystals ranging in composition from $Ab_1 An_1$ to $Ab_3 An_1$.

These felspars are loosely aggregated together and appear as if floating in the abundant analcite which fills all the interspaces. The latter is fresh and limpid, and shows beautiful cross-hatching similar to that of leucite. Numerous idiomorphic crystals of ægirine and of brown and blue soda-amphibole (barkevicite and arfvedsonite) are enclosed in the analcite. These are frequently found in confused, tangled crystal aggregates at one side, or in one of the angular bays, of an analcite area. There can be but little doubt that these crystals gravitated into the lower portion of the analcite area as the latter was situated during the cooling of the magma. This fact, together with the perfect idiomorphism of most of the constituents of the rock, affords impressive testimony, not only of the long duration and high degree of liquidity of the residual magma, but also of the primary nature of the analcite.

In the more basic varieties of the rock titanaugite is a prominent constituent. It is of a variable purplish-brown tint, becoming green on the margins where it adjoins an alkali felspar or an area of analcite. It is frequently shot through with large skeletal crystals of ilmenite in blebs, patches, and strings extending right through and beyond the boundaries of the crystals. These form the large lustre-mottled aggregates prominent in some hand-specimens. Apatite occurs abundantly in small bifid crystals usually enclosed in the analcite.

[1] This term is used throughout for augite with the purple-madder tint supposed to indicate a high titanium and alkali content.

The mineral composition of the two principal varieties, estimated by the Rosiwal method, is given in Table I.

TABLE I.

	I.	II.
Analcite	8·1	15·9
Alkali-felspar	54·7	66·8
Labradorite	5·2	—
Titanaugite	15·1	—
Ægirine	3·3	9·3
Soda-amphibole	1·6	4·3
Titano-magnetite	7·9	2·5
Olivine	2·6	—
Apatite	1·5	1·2

I. Main mass of intrusion.
II. Acid bands and veins.

Chemical composition. The normal analcite-syenite of Howford Bridge has been analysed by Dr. Dittrich of Heidelberg with the result set forth in column I of the Table below. With it are tabulated for comparison the analyses of three other rocks.

TABLE II.

	I.	II.	III.	IV.
SiO_2	56·44	55·95	58·46	60·15
TiO_2	1·16	·45	·28	—
Al_2O_3	15·54	18·60	16·56	18·04
Fe_2O_3	3·27	2·60	5·69	4·44
FeO	3·67	5·22	2·59	1·82
MnO	—	—	—	·13
MgO	1·73	3·17	·62	·98
CaO	4·16	3·97	2·62	1·68
Na_2O	5·81	5·15	6·23	6·07
K_2O	4·27	4·00	5·44	4·15
H_2O+	2·06	·50	1·21	2·06
H_2O-	·44			
CO_2	·97	—	·04	
P_2O_5	·83	—	·23	—
Cl	—	—	·29	—
	100·35	99·61	100·26	99·52

I. Analcite-syenite, Howford Bridge, Mauchline, Ayrshire.
II. Ditroite, Ampangarinana, Madagascar: Lacroix, Nouv. Arch. du Mus. (iv), vol. iv, p. 19, 1902.
III. Pulaskite, Cabo Frio, Rio de Janeiro. Quoted in Rosenbusch, *Elem. der Gest.*, 3rd ed., 1910, p. 128.
IV. Phonolitic trachyte, North Berwick Law, East Lothian. Quoted in *Geology of East Lothian*, Mem. Geol. Surv., 1910, p. 130.

The analysis shows that this analcite-syenite belongs to the group of the alkali-syenites, and not to the felspathoidal group. The Madagascan ditroite quoted does not contain nearly so much alkalies as the usual run of nepheline-syenites, and seems rather to belong to the alkali-syenites. The comparatively high lime content in the Howford Bridge rock, due to the abundance of pyroxenes, is to be noted, as it is a point of difference with the majority of the alkali-syenites. This feature links the rock to the umptekites, but no very concordant analysis of the latter could be discovered. Amongst previously described Scottish Carboniferous rocks, the phonolitic trachytes of East Lothian, notably that of Berwick Law, show decided chemical affinities with the Howford Bridge rock, as may be seen by comparing Analysis IV with I. These rocks are said to contain analcite and probably pseudomorphs after nepheline.[1]

Towards the base of the Howford Bridge sill the proportions of titanaugite, iron-ore, and labradorite increase rapidly, and the rock passes into an essexite-dolerite identical with those described later (in Part II). The contact facies is a dense splintery basalt of similar composition. A thin layer of essexite-dolerite also forms the upper contact of the sill, but it passes rapidly downwards into the normal analcite-syenite. The sheath of essexite-dolerite surrounding the analcite-syenite is penetrated by numerous irregular anastomosing veins of the latter rock. It is probable that in this sill we have a case of gravity differentiation similar to that of the Lugar (pp. 75, 76) and Benbeoch (*infra*) masses.

Another occurrence of analcite-syenite is known from a sill intruding the 'Permian' lavas in the Dippol Burn, 1½ miles north of Ochiltree. Here, however, the analcite-syenite occurs in thin contemporaneous stratiform bands in an essexite-dolerite which forms the major part of the sill. The rock is generally similar to that described above, but the rhomboid form of the felspars and the trachytoid structure is accentuated. Veins of analcite-syenite occur also in the essexite-dolerite of the Trabboch Burn, near Stair (see Part II of paper).

Analcite-syenite of a different type is to be found in the numerous aplitic veins which penetrate many of the teschenites. These are fine-grained light-coloured rocks forming veins up to 2 inches in width. In the Necropolis (Glasgow) teschenite the veins are composed of a plexus of plates and idiomorphic prisms of orthoclase, sometimes moiré and perthitic, embedded in an abundant groundmass of dusty analcite. A little analcitized labradorite may also be present. Some flakes of a bleached biotite and a few skeletal crystals of ilmenite are the only ferromagnesian minerals to be found. In one slide, however, there are a few needles of ægirine, and some sections, the shape and mode of decomposition of which suggest the presence of nepheline. The texture is fine and even-grained, and the rock might be termed analcite-syenite-aplite. Veins occur in many other teschenites, notably the Galston type, in which they are quite coarse-grained hypidiomorphic syenites.

2. *Teschenite.*—Rocks belonging to this group are very abundant, and are fairly uniform in character. The sill of the Necropolis Hill,

[1] Mem. Geol. Surv., *Geology of East Lothian*, 1910, p. 130.

Glasgow, is a typical example. This rock has been often described, first by Teall,[1] later by Macnair,[2] and finally a complete account has recently been given by Bailey.[3] Hence it is unnecessary to describe the rock in this place. It seems appropriate to designate this common and widespread variety of teschenite as the *Glasgow type* since it was first described by Teall from the Glasgow occurrences. The mineral composition of the Lugar teschenite, given in column II, Table III, may serve as the quantitative definition of the Glasgow type, as it is practically identical with the Necropolis Hill rock.

The contact facies is a black basaltic rock consisting microscopically of a fine-grained holocrystalline aggregate of plagioclase, augite, olivine, and analcite, frequently with abundant biotite and red hornblende. The ferro-magnesian minerals, especially olivine and biotite, are distinctly more abundant than in the coarse central facies, and the rock takes on a lamprophyric habit. If occurring as an independent mass it would doubtless be assigned to the camptonite group.

Rocks of the Glasgow type are abundant in the east of Glasgow, and also at Shettleston, still farther east. In Ayrshire they occur near Old Cumnock, Skares, Lugar, Galston, Stewarton, Ardrossan, and Troon. In Arran perfectly similar rocks are found intruding the Triassic at Dippin Head.[4] Numerous occurrences of teschenite from the Lothians have been described and some analysed.[5]

A sub-variety of the Glasgow type occurs at Galston, Shettleston, and elsewhere. It is characterized by the abundance of large pseudo-porphyritic augite crystals and has a distinctive appearance in hand-specimens. The large augites are set in a fine-grained groundmass of plagioclase, orthoclase, and analcite, which is practically free from ferroclase-magnesian minerals. A little biotite, olivine, and ilmenite may be present. This rock may be referred to as the *Galston type*.

A quite distinct variety of teschenite occurs in a group of sills at Cathcart, near Glasgow. It is a fine-grained nepheline-bearing rock which may be regarded as intermediate between the true teschenites and the theralites of the Barshaw type (p. 80). It consists of plagioclase, titanaugite, olivine, red hornblende, analcite, nepheline, and ilmenite. Olivine is in greater and analcite in less quantity than in the Glasgow type. Nepheline is fairly abundant in broad plates which envelop felspars and flakes of biotite. In addition this rock differs from the Glasgow type in the habit of the augite, which occurs mostly in polysomatic groups of small subhedral grains. This, together with the finer grain and the greater abundance of the femic constituents, gives it quite a different aspect in thin section to that of the Glasgow type. It may therefore be called the *Cathcart type*. Similar rocks occur at the Linn Falls on the River Cart, near Cathcart, the Glengyron railway cutting near Old Cumnock, and in

[1] *Brit. Petrog.*, 1888, p. 194; see also pl. xiii.

[2] Trans. Glasgow Geol. Soc., vol. xiii, pt. i, pp. 79–82, 1907.

[3] Mem. Geol. Surv., *The Geology of the Glasgow District*, 1911, pp. 114–16, 132–3.

[4] Harker, Mem. Geol. Surv., *Geology of North Arran, etc.*, 1903, p. 112.

[5] Mem. Geol. Surv., *Geology of East Lothian*, 1910, p. 114, and *Geology of the Neighbourhood of Edinburgh*, 1910, pp. 293–301.

the contact facies of the Ardrossan picrite-teschenite sill. Mr. Bailey has described the rock as nepheline-teschenite, and regards it as allied to the porphyritic essexite of Lennoxtown.[1] Some of the teschenites show leucocratic and melanocratic modifications. This is well seen in the extraordinary complex of the Lugar teschenite-picrite (p. 77). The leucocratic variety is a coarse-grained pinkish rock rich in analcite and orthoclase, whereas in the melanocratic variety the felspar and analcite total only about 20 per cent of the mass. In texture this rock resembles the Cathcart rather than the Glasgow type.

Diagrammatic longitudinal section of the picrite-teschenite sill, Lugar. T = Teschenite; Th = Theralite; P = Picrite. Not drawn to scale. Length of sill 3¾ miles, thickness 140 feet.

3. *Picrite-teschenite.*—In two or three cases the differentiation of a basic teschenite has given rise to a considerable body of ultra-basic rock. The most remarkable instance of this occurs at Lugar in Central Ayrshire.[2] This intrusion, which is magnificently dissected by the Bellow and Glenmuir Waters, contains an extraordinary assemblage of analcite and nepheline-bearing rocks. It is a sill about 140 feet in thickness, and intrudes a white sandstone belonging to the Millstone Grit. At both upper and lower contacts is a black basaltic rock grading insensibly, through fine-grained varieties, into a typical coarse teschenite of the Glasgow type. Below the upper teschenite comes about 10 feet of beautifully fresh theralite with abundant nepheline. This rock, of which there are two varieties, differs from the Barshaw rock (p. 80) in several particulars, and will be described under the head of theralite. It rests upon a great thickness of picrite or peridotite, which, in its turn, rests upon the lower teschenite, but without the intervention of a theralite zone. The ultra-basic rock occupies about five-eighths of the total thickness of the sill (see Figure).

In hand-specimens the picrite is medium- to coarse-grained, blackish-green in colour, and frequently exhibits flashing, lustre-mottled plates of hornblende. Microscopically it is composed of olivine in more or less rounded grains, ranging up to half an inch in diameter, and in all stages of alteration to blue, green, yellow, and colourless serpentine. It is often quite fresh and forms about 65 per cent of the rock. The next most abundant constituent is titanaugite, which totals about 21 per cent. It occurs as numerous, minute, euhedral grains in little clusters or polysomatic groups wedged in between the olivines, and where the latter is altered, enveloped in serpentine. Hornblende occurs to the extent of 10 per cent in large irregular plates

[1] *Summary of Progress of Geological Survey for 1908*, 1909, p. 45; also Mem. Geol. Surv., *Geology of the Glasgow District*, 1911, p. 131.

[2] Boyle, Trans. Glasgow Geol. Soc., vol. xiii, pt. ii, pp. 202–23, 1903.

poikilitically enclosing both olivine and augite. It is a red-brown variety belonging to barkevicite. A very little ilmenite (3 per cent) is enclosed in the hornblende, but the rock is remarkable for the scarcity of iron-ore. A few flakes of red biotite, of later crystallization than the augite, are seen occasionally. There is no apatite, as that mineral always seems to go with abundant analcite. This rock differs from the Inchcolm type[1] in the absence of felspar, the abundance of hornblende, and the granular habit of the augite. It may be referred to as the *Lugar type*. The rock is so rich in olivine that it should perhaps be called a peridotite. Towards the top of the ultra-basic mass, however, the proportion of olivine lessens, and a considerable quantity of plagioclase and analcite comes in. The percentage mineral composition of this rock is shown in column VII of Table III (p. 77). There is also a variety in which the augite totals over 50 per cent of the mass (column VI, Table III). These rocks are true picrites, comparatively rich in the bisilicate constituents, and containing some felspar.

It is not intended here to discuss the cause of the remarkable differentiation which has given rise to the varied assemblage of rock-types within the Lugar complex. Briefly the writer believes that it is due to a stratification of the magma under the influence of gravity—a separation of heavier from the lighter and more volatile constituents—which began before crystallization commenced and continued for some time after. This stratification took place within a shell of viscous or solid material slowly growing out from both contacts, and was rendered possible by the abundance of a water-rich mother-liquor which subsequently crystallized as analcite. The presence of this mother-liquor is believed to have maintained the magma in a state of great liquidity for a long period of time, and thus facilitated differentiation under the influence of gravity. Numerous facts and observations, for the full statement of which a later detailed paper must be consulted, give support to this hypothesis.

Table III shows the percentage mineral composition of the rock-types appearing in the complex, arranged as a series from the top to the bottom of the sill. These have been obtained by the Rosiwal method, to which these fresh, medium-grained rocks lend themselves admirably.

A picrite-teschenite sill, very similar to that at Lugar, occurs on the Ayrshire coast at Castle Craigs, Ardrossan. It has been described by Falconer,[2] who, whilst noting the abundance of analcite, has identified the rocks as hornblende-dolerite and picrite. Close to the upper contact the rock is a nepheline-teschenite of the Cathcart type, containing abundant red hornblende, which is indeed a characteristic mineral of the whole suite. Nepheline is also fairly abundant. This rock passes downwards into a teschenite of the Glasgow type, but with more hornblende than the normal variety. According to Falconer the picrite, which belongs to the Inchcolm type, occupies more than half the thickness of the sill. He describes the underlying teschenite as more nearly allied to the picrite than the overlying rock.

[1] Campbell & Stenhouse, Trans. Edinb. Geol. Soc., vol. ix, pt. ii, pp. 121–34, 1907.

[2] Trans. Roy. Soc. Edinb., vol. xlv, pt. iii, pp. 601–11, 1907.

TABLE III.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Plagioclase	23·2	27·9	6·6	23·3	16·4	—	5·7	—	28·9	34·5
Orthoclase	10·2	5·6	—	—	—	—	—	—	—	2·9
Analcite	16·1	19·9	12·2	—	—	13·4	8·8	—	13·8	15·5
Nepheline	—	—	—	12·6	16·6	—	—	—	—	—
Titanaugite	28·1	27·2	24·0	36·1	35·9	56·6	26·1	20·5	39·9	27·3
Hornblende	—	—	18·1	—	12·2	12·7	8·6	10·0	—	—
Olivine	10·6	7·5	32·5	18·6	8·7	11·1	49·1	65·2	4·6	12·9
Biotite	3·4	1·5	3·7	3·6	6·7	—	·4	2·0	2·9	2·1
menite	7·1	9·3	1·9	4·2	2·5	5·1	1·0	2·3	9·9	3·7
Apatite	1·3	1·1	1·0	1·6	1·0	1·1	·3	—	—	1·1

I. Fine-grained banded teschenite, near upper contact, Bellow Water.
II. Teschenite, with abundant analcite, near upper contact, Bellow Water.
III. Melanocratic teschenite, below II.
IV. Theralite, below III.
V. Hornblende-theralite, below III.
VI. Augite-picrite, top of ultra-basic mass, Glenmuir Water.
VII. Olivine-picrite, top of ultra-basic mass, Glenmuir Water.
VIII. Hornblende-peridotite, main ultra-basic mass, Glenmuir Water.
IX. Teschenite, between base of peridotite and X, Glenmuir Water.
X. Teschenite, lower contact, Glenmuir Water.

Whilst some of the rocks from the upper contact contain nepheline, the theralite zone, so conspicuous in the Lugar sill, is absent.

Another picrite-teschenite complex is intruded as an intricately ramifying mass into the agglomerate of the Carskeoch vent, near Patna. Among the rocks represented here are picrite, teschenite, lugarite, monchiquite bearing huge crystals of hornblende and biotite, and essexite. Ultra-basic *couches* occur in the interior of some of the kylite sills, and will be described later under the head of kylite (see Part II).

4. *Lugarite.*—A very remarkable rock with affinities to the leucocratic teschenites and to the ijolites occurs in the heart of the Lugar teschenite-picrite complex as a sill about 4 feet thick, and as thin veins or dykes penetrating the picrite. In hand-specimens it has a very striking appearance. It generally shows a grey or greenish-grey groundmass crowded with lustrous black prisms of barkevicite ranging up to 3 inches in length, and frequently arranged in rude stellate groups. Shorter and stouter black crystals occur which are recognizable as augite. In thin section the rock is seen to be composed of analcite, nepheline, plagioclase, barkevicite, titanaugite, ilmenite, and apatite. The analcite (with nepheline) forms about 50 per cent of the rock, and is usually decomposed with the formation of a brown dust. It may be recognized by the fact that it occasionally clears to a limpid patch of undoubted analcite, and by the frequently complete analcitization of the enclosed felspars. Titanaugite and barkevicite occur as large euhedral crystals, the extraordinarily perfect forms of which testify to the freedom of their crystallization, and the liquidity of the magma in which they were developed. The augite is of a deep-purple colour with an intense pleochroism; the barkevicite is red brown, also with strong pleochroism. In the prevailing variety of the rock titanaugite occurs to the extent of 20 per cent, and

barkevicite 15 per cent. The felspar is also perfectly euhedral, and very zonal. The determination of its composition is difficult because of the analcitization it has undergone, but it is probably a labradorite of the usual composition—$Ab_1 An_1$. It forms about 10 per cent of the rock. Ilmenite passing over to leucoxene totals 3 per cent, and apatite, which crowds the groundmass, about 2 per cent. Nepheline occurs in the groundmass, but decomposition renders the recognition difficult. Its presence is indicated by a streaky micaceous alteration product, and by faint hexagonal or rectangular outlines occasionally discernible in the groundmass. The veins penetrating the Lugar picrite differ from the above in containing no titanaugite. The proportion of barkevicite and apatite is greater. Rocks closely resembling the above occur as schlieren, veins, and irregular patches towards the top of the exposure of theralite at Barshaw House, near Paisley. Recognizable nepheline is considerably more abundant, however, than in the Lugar rock, and there are numerous small crystals of ægirine. The Barshaw theralite here falls naturally into its place as the melanocratic facies of lugarite.

This rock stands apart from the recognized types of igneous rocks, and can be fitted with no current name. It has therefore been called *lugarite* after the type locality. As far as the analcite content goes it resembles the heronite of Coleman.[1] Considering its composition and its association with the Barshaw theralite, which closely resembles the Madagascan bekinkinites, lugarite evidently has affinities with the ijolites, and may be regarded as an ijolite in which the greater part of the nepheline has been displaced by original analcite, and in which barkevicite is a prominent constituent as well as augite.

A rock with some resemblance to lugarite, but with considerably more felspar, occurs at the upper contact of a great essexite-dolerite sill at Howcommon Quarry, Craigie.

5. *Monchiquite.*—A remarkable rock belonging to this group is found in association with a picrite-teschenite complex at Carskeoch Hill, near Patna. In hand-specimens it is black and compact, and carries numerous huge phenocrysts of hornblende and biotite ranging up to 3 inches in diameter. Microscopically it consists of a crowded mass of idiomorphic granules of pale augite, with numerous crystals of magnetite and flakes of biotite. Olivine occurs abundantly as small micro-porphyritic crystals. All these are enveloped in a scanty but pervading groundmass of analcite, which also occurs in numerous irregular areas where its specific characters may be easily recognized. It is partially carbonated, and the areas are surrounded by a thick zone of augite granules many of which are aligned tangentially to the margin. The phenocrysts consist of the above-mentioned large hornblendes, which are of a red barkevicitic variety, and biotite, also a red variety. A little red hornblende also occurs in the groundmass. The rock contains numerous ocelli of various kinds, the commonest being a simple radial aggregate of augite prisms.

This rock is very similar to the porphyritic monchiquite of Kilchattan, Colonsay.[2] It differs, however, in the presence of olivine

[1] Harker, *Petrology for Students*, 4th ed., 1908, p. 132.

[2] *Summary of Progress of Geological Survey for 1909*, 1910, p. 52.

and the absence of nepheline. An almost identical rock has been described by Boulton from the Old Red Sandstone between Chepstow and Usk, in Monmouthshire.[1] Rocks of monchiquitic habit and composition, but without porphyritic constituents, occur as the contact facies of some kylite and teschenite sills, notably at Craigie and Kilmaurs.

B. *Rocks with conspicuous Nepheline.*

Rocks belonging to this group occur in far less abundance than those characterized by analcite. They comprise theralites and essexites, with an almost ultra-basic type—kylite. The latter, and the essexites also, contain only a small quantity of nepheline, but are treated here because of their relationship to the conspicuously nepheline-bearing rocks.

1. Theralite. (a) *Bellow type.*—This rock has been mentioned in connexion with the teschenite-picrite sill of Lugar, in which it forms a stratiform mass, about 10 feet thick, intervening between the upper teschenite and the picrite. In hand-specimens the rock is grey to black in colour, and very fine-grained in texture. Microscopically it is composed of plagioclase, nepheline, titanaugite, olivine, biotite, ilmenite, and apatite in the proportions shown in Table III, column IV (p. 77). Augite is present in two forms—as innumerable minute prismoid grains embedded in the felspathic groundmass, and as larger euhedral pseudo-porphyritic crystals of a deep-purple tint. Olivine occurs in large, fresh, more or less rounded crystals full of magnetite-blackened fissures. Biotite, whilst forming numerous independent flakes, is also commonly associated with very irregular skeletal crystals of ilmenite. All these constituents are embedded in a groundmass of fresh anhedral felspar and turbid nepheline. The felspar is a highly zonal plagioclase, ranging in composition from $Ab_1\ An_1$ to $Ab_3\ An_1$. It is occasionally bordered by a little orthoclase. The nepheline is usually turbid owing to the development of a characteristic streaky micaceous alteration-product, which is arranged parallel to the cleavage. It builds rather large plates to which the felspar is idiomorphic. The felspar and nepheline are crowded with needles of apatite. The rock has a characteristic poikilitic fabric, the granular ferro-magnesian constituents being enclosed in the broad plates of plagioclase and nepheline. The felspars show systems of radiating fissures springing from enclosed olivine where the alteration of the latter has given rise to serpentine and consequent expansion.

Another variety (Table III, column V) shows a considerable development of barkevicitic amphibole, with a diminution of olivine and plagioclase and an increase in the amount of nepheline. This rock approaches the Barshaw type described below.

The rocks described above belong to the theralite group, but have a distinctly melanocratic facies as compared with typical theralites such as that of Duppau, Bohemia. They differ from the kylite group described below in the small proportion of olivine and the abundance of nepheline. Their textural peculiarities and mineral composition entitle them to rank as a distinct type, which may be named the *Bellow type*, after the stream in which they are best exposed. Some thin anastomosing veins penetrating the Bellow rock show the same

[1] Proc. Geol. Soc., 1911, p. 104.

constituents, with the addition of analcite; but the salic and femic minerals are here more nearly on an equality, as in the typical theralites.

Theralites of a more normal type occur at Garlaff and Knockterra, near Old Cumnock. In these there is approximate equality between the amounts of the salic and femic constituents. The deep-purple titanaugite builds large subhedral plates which ophitically enclose small laths of felspar. There is no granulitic generation of augite. Fresh olivine is fairly abundant. The nepheline is decomposed, but may be recognized by its characteristic alteration.

(b) *Barshaw type.*—Mr. E. B. Bailey has described a theralitic rock from a small sill at Barshaw House, near Paisley.[1] The chief femic constituents are titanaugite and dark-brown soda-amphibole, with sparse olivine and iron-ores. Labradorite and large allotriomorphic plates of nepheline form the remainder of the rock. The nepheline is mostly decomposed to various secondary products, chlorite, and analcite; but the latter may also be primary. The rock is decidedly melanocratic as may be gathered both from microscopic study and the chemical analysis.[2] The mineral constituents are the same as those of lugarite, but analcite is more abundant in the latter, which is undoubtedly the leucocratic facies of the Barshaw type. This conclusion is supported by the fact that towards the top of the Barshaw exposure occur contemporaneous bands and veins of lugarite; but the nepheline in this rock is much fresher and more abundant than in the type-occurrence of Lugar. The Barshaw exposure[3] also provides mesocratic types intermediate between theralite and lugarite. With an increase in the salic constituents, especially analcite, goes a significant increase in the idiomorphism of the titanaugite and barkevicite, which culminates in the very perfect forms displayed by these minerals in lugarite.

A rock which probably belongs to the Barshaw type occurs in the Inner Nebbock sill at Saltcoats, Ayrshire. Here, however, the felspar and nepheline have entirely disappeared, and fresh titanaugite, barkevicite, serpentinized olivine, and ilmenite are enclosed in a groundmass of brilliantly polarizing zeolites.

(*To be concluded in the March Number.*)

V.—The Fossil Flora of the Ingleton Coal-field (Yorkshire).

By E. A. Newell Arber, M.A., F.G.S., Trinity College, Cambridge, University Demonstrator in Palæobotany.

THE Upper Carboniferous rocks of the Ingleton Coal-field in North-West Yorkshire present a difficult study, and at the present time they are very imperfectly known.[4] As mapped by the

[1] *Summary of Progress of Geological Survey for 1908*, 1909, p. 44; also Mem. Geol. Surv., *The Geology of the Glasgow District*, 1911, p. 134.

[2] *Summary of Progress of Geological Survey for 1907*, 1908, p. 55. This rock is called "bekinkinite or theralite" by Bailey, Mem. Geol. Surv., *Geology of the Glasgow District*, 1911, p. 134.

[3] *Summary of Progress of Geological Survey for 1908*, 1909, p. 44.

[4] J. R. Dakyns, etc., *The Geology of the Country around Ingleborough* (Mem. Geol. Surv.), 1890. See also Davis & Lees, *West Yorkshire* (London, 1878), p. 167

Geological Survey,[1] there is apparently a perfect succession, passing up from the Yoredales, through the Millstone Grits, to the Lower and Middle Coal-measures. The coal-measures are in part overlain by a series of red rocks, which have been assigned to the Permian, as in the case of other of the Midland Coal-fields. In the index of the Survey map of the north-eastern portion of the coal-field, the Deep Coal is taken as the top of the Lower, and the bottom of the Middle Coal-measures.

So far as I am aware no fossil plants have hitherto been recorded from the coal-field.[2] The specimens discussed here are in the Sedgwick Museum, Cambridge,[3] and were collected during the visits of Professor Hughes' field classes to the district in 1886 and on other occasions. Another collection, formed by the donor from the same locality, has recently been presented to the Museum by Miss Elles. The plants occur both in the shales and also in the clay ironstone nodules, as is so commonly the case in the Midlands. They were chiefly obtained from the waste heap of Newfield Pits, Ingleton. The section of this colliery is published in the Survey Memoir.[4] The Coal-measures penetrated in these pits are only 1144 feet in thickness, and include the Crow, Main or Four Foot, and the Six Foot Coals. The specimens in shale presented by Miss Elles were obtained *in situ* from the shales forming the roof of the Six Foot Coal. The ironstone nodules no doubt occur in more than one bed. They are frequent in the so-called 'soapstone', or argillaceous shales, above the lowest seam. There is thus little doubt that all the specimens described here were closely associated.

The flora of these beds, though small, is of much interest. There is a considerable variety of fern-like fronds, including one belonging to *Sphenopteris*, which may be compared with *S. Laurenti*, Andræ, but which is not sufficiently well preserved to be determinable specifically. There are several Neuropterids, *Neuropteris acuminata* (Schloth.) being frequent. *N. heterophylla*, Brongn., *N. obliqua* (Brongn.), and *N. gigantea*, Sternb., also occur. Cyclopterid pinnules of the type of *Cyclopteris trichomanoides*, Sternb., are present. *Alethopteris* is probably represented by three species—*A. lonchitica* (Schloth.), *A. decurrens* (Artis), and *A. davreuxi* (?) (Brongn.). *Mariopteris muricata* (Schloth.) is frequent, and it is especially interesting to find that several examples of *Dictyopteris sub-Brongniarti*, Grand'Eury, have been collected, and that this plant appears to be of fairly frequent occurrence.

The Lycopods are represented by stems of *Lepidodendron obovatum*, Sternb., and *L. lycopodioides*, Sternb., as well as a large number of leafy twigs, some of which no doubt belong to the latter species. A single specimen of *Lepidophloios laricinus*, Sternb., is present.

[1] As is well known, this coal-field is intersected by four sheets of the Geol. Surv. Maps. Sheets N.S. 49 (= 98 S.E. of O.S.) and N.S. 50 (= 97 S.W. of O.S.), however, contain the greater part of the area of Upper Carboniferous rocks.

[2] Davis & Lees (ibid., p. 169), however, noticed the occurrence of fossil plants in the ironstone nodules of the Coal-measures.

[3] Carb. Plant. Coll., Nos. 1114, 1360–1, 1364, 1367–8, 1370–1, and 2178–2209.

[4] Dakyns, ibid., p. 81.

There are also several examples of *Lepidostrobus*, and, in some of the shales, masses of rootlets, of unknown affinity, are conspicuous.

The following is a list of the species which were recorded :—

FILICALES OR PTERIDOSPERMS.

Sphenopteris cf. *S. Laurenti*, Andræ.
Neuropteris acuminata (Schloth.).
N. heterophylla, Brongn.
N. obliqua (Brongn.).
N. gigantea, Sternb.
Alethopteris lonchitica (Schloth.).
A. decurrens (Artis).
A. davreuxi (?) (Brongn.).
Mariopteris muricata (Schloth.).
Dictyopteris sub-Brongniarti, Grand'Eury.

LYCOPODIALES.

Lepidodendron oboratum, Sternb.
L. lycopodioides, Sternb.
L. sp.
Lepidophloios laricinus, Sternb.
Lepidostrobus sp.

This flora is quite a typical Middle Coal-measure assemblage, and there is thus no doubt that the coals worked at the Newfield pits belong to that horizon. Several of the species are unknown from the Lower Coal-measures, especially *Alethopteris Davreuxi* (Brongn.) and *Lepidophloios laricinus*, Sternb. *Dictyopteris sub-Brongniarti*, Grand'Eury, have been recorded only from the Middle Coal-measures.

As a whole the Ingleton Coal-measures seem to be closely related to the Yorkshire Coal-field, and all the species recorded here, except *Dictyopteris sub-Brongniarti*, Grand'Eury, are already known from that coal-field.

VI.—New Devonian Fossils from Cornwall.

By Ivor Thomas, D.Sc., Ph.D., F.G.S.
(Communicated by permission of the Director of the Geological Survey.)

A SHORT time ago a Devonian fossil of considerable interest was found in the grits of the Ladock neighbourhood. It had been found by a workman in a road-heap on the Grampound Road and was placed for preservation in the Truro Museum. A cast was kindly made by Mr. C. Davies Sherborn and presented to the Museum of Practical Geology [22466]. This fossil was named *Orthis* sp., and is referred to as such in the Memoir of the Geological Survey on the geology of the country near Newquay (p. 35).

More recently Messrs. C. Davies Sherborn and Upfield Green were fortunate enough to secure another example of this Brachiopod from the Ladock quarry. Mr. Upfield Green succeeded through patient developing of the second specimen in exposing the muscle impressions of one valve, and this has justified the previous allocation of the specimens to *Orthis*. The second example has been presented by Mr. C. D. Sherborn to the British Museum (Nat. Hist.).

Though the preservation of the specimens leaves much to be desired, it is considered advisable to publish this note in order to induce further careful search in a locality hitherto considered to be practically unfossiliferous.

First example.—This shows the two valves in conjunction, with prominent umbones and well-developed area in the brachial valve. The latter has a broad sinus, due probably in part to deformation, as the opposite valve has no appreciable fold. The surface is ornamented with strong costæ, which are widely spaced, the breadth of each

interspace being about twice the thickness of a costa. Smaller ones are occasionally interpolated. The middle of the anterior margin of the brachial valve has six costæ within a space of 10 mm., while the maximum length of the shell is 26 mm. and the maximum width 41 mm.

Second example.—This specimen does not show the costation so well as the preceding, though the anterior portion is somewhat better preserved. At the anterior part of the middle portion of the valve there are about eleven costæ within a space of 10 mm. The greatest length of the preserved part of the shell, consisting only of the brachial valve, is 23 mm., while the greatest preserved width is 52 mm. The fairly high triangular area lies in the plane of the shell, while the cast of two strong delthyrial supporting plates, imperfectly preserved, and an open delthyrium with a strong cardinal process are present. The process is produced forward as a strong median septum for a distance of about 16 mm. The adductor muscle-impressions cover a pear-shaped area and are divided into two portions by the median septum. Each of these portions is further subdivided by two longitudinal grooves, another groove forming the lateral and anterior boundary of each half of the muscular area. The whole muscle-impression has a maximum length of 17 mm. and a maximum width of 10 mm.

Both specimens are compressed along the longitudinal axis, so that the width-measurement is greater than in the original state.

Affinities.—No described form appears to agree with this species. The deformation of the examples makes comparison difficult, but they suggest nearest relationship to the robust form described by Professor Kayser[1] and Dr. Drevermann[2] from the Siegener Grauwacke as *Orthis personata*, Zeiler. The British form, however, is more coarsely costate and has a more rotund and less elongated muscular area in the brachial valve.

Locality and Horizon.—Mr. C. Davies Sherborn informs me that the first-mentioned specimen was obtained by a road-mender on a road-heap on the road to Grampound and about two miles south of Ladock. Other 'shells' were said to have been present with it on the same heap. The second fossil is in undoubted Grampound Grit matrix, and was found by a quarryman named Bennett in response to a reward offered by Mr. Upfield Green. Mr. Green was informed of the discovery by the Ladock schoolmaster, Mr. Clemmow. The quarry is on the west side of the river over the bridge from the inn.

Though there exists a certain divergence of opinion regarding the correlation of the Grampound Grit with beds of other localities, there is now practical unanimity in allocating it to a Lower Devonian horizon. Mr. Ussher[3] defines the term as a "name given to the

[1] E. Kayser, "Beiträge zur Kenntniss der Fauna der Siegenschen Grauwacke": Jahrb. d. K. p. geol. Landesanst., Bd. xi (1890), p. 98, pl. xi, figs. 3–5; pl. xii, figs. 1–4; Berlin, 1892.

[2] F. Drevermann, "Die Fauna der Siegener Schichten, etc.": *Palæontographica*, Bd. l, p. 264, pl. xxxi, figs. 1–8, Stuttgart, 1904.

[3] Mem. Geol. Surv., *The Geology of the Country around Bodmin and St. Austell*, Sheet 1" 347, p. 25, London, 1909.

arenaceous and conglomeratic rocks, which extend westward from Pentewan through Grampound, by me in 1890, from the descriptions of the type in De la Beche's Report, pp. 83 and 92, near Pentewan and Grampound". Messrs. C. Davies Sherborn and Upfield Green[1] consider the Grampound Grit to be equivalent to the 'Portscatho' of Mr. J. B. Hill[2] and correlate it with the Upper Gedinnian of the Continent. The Portscatho series is placed by Mr. Hill[2] in the Lower Palæozoics. Mr. J. H. Collins[3] was disposed in his earlier work to place the Ladock Beds in the Upper Silurian, but later[4] he appears inclined to assign them to the Lower Devonian. The correlation proposed by Mr. Green is questioned by Mr. Ussher,[5] who, however, agrees that the Grampound Grits are of Lower Devonian age and includes them in the Meadfoot Group.[6] They are also placed in the 'Lower Devonian' by Mr. Clement Reid,[7] but higher in position than according to Mr. Ussher's view.

It would be unsafe to attach too much weight to the evidence of the imperfect specimens above described, though their characters certainly suggest that the Grampound Grit was deposited during Upper Gedinnian or possibly 'Siegener Schichten' time.

REVIEWS.

I.—The Wealden Fishes of Belgium.

Les Poissons Wealdiens de Bernissart. By Dr. Ramsay H. Traquair, F.R.S. Mém. Mus. Roy. d'Hist. Nat. Belgique, vol. vi, pp. 1–65, pls. i–xii, 1911.

FOR many years palæontologists have eagerly awaited a description of the large collection of fossil fishes from the Wealden formation of Bernissart, Belgium, found associated with the remarkable skeletons of *Iguanodon* and other reptiles of which a preliminary account was published more than twenty years ago by Professor L. Dollo. The long delay, however, has not been altogether in vain; for the Brussels

[1] Upfield Green, "Note on the Correlation of some Cornish Beds with the Gedinnian of Continental Europe": Geol. Mag., n.s., Dec. V, Vol. I, pp. 403–7, London, 1904.

[2] J. B. Hill, "On the Relation between the Older and Newer Palæozoics of West Cornwall," Geol. Mag., n.s., Dec. V, Vol. III, pp. 206–16, London, 1906; Mem. Geol. Surv., *The Geology of Falmouth and Camborne*, Sheet 1" 352, p. 33, London, 1906.

[3] J. H. Collins, "Preliminary Note on the Stratigraphy of West Cornwall," Trans. Roy. Geol. Soc. Cornwall, vol. x, p. 2, Penzance, 1879–87; "On the Geological Structure of the northern part of the Meneage Peninsula," ibid., p. 47.

[4] J. H. Collins, "On the Geological Age of Central and West Cornwall": Journ. Roy. Inst. Cornwall, vol. viii, pt. ii, p. 163, Truro, 1884.

[5] W. A. E. Ussher, "The Devonian Rocks of Cornwall": Geol. Mag., n.s., Dec. V, Vol. I, pp. 587–91, London, 1904.

[6] Mem. Geol. Surv., *The Geology of the Country around Bodmin and St. Austell*, Sheet 1" 347, p. 2, London, 1909.

[7] Ibid., *The Geology of the Country near Newquay*, Sheet 1" 346, pp. 30–5, London, 1906.

Museum has at last been able to obtain the services of Dr. Traquair for the work, and he has now accomplished it in a manner which only his experience, skill, and patience have made possible. The fossils are by no means in the best state of preservation for study, being crushed in a grey clay and not exhibiting the cranial osteology; but they are nearly three thousand in number, and they have been so exhaustively examined and compared by Dr. Traquair that the principal distinctive characters of most of the species are well made out.

The fish of perhaps the greatest interest is a new species of *Coccolepis* (*C. macropterus*), which is a typical member of the Palæoniscidæ, an ancient family not hitherto discovered above the Purbeck formation. Dr. Traquair publishes good restored figures of this important fish, showing both the internal skeleton of the trunk and an outer view, which lacks only the details of cranial osteology. It is the largest known species, except *C. australis* from the Jurassic of New South Wales; and its Acipenseroid pelvic fin-supports are clearly shown, as already described in this earlier form.

Of *Lepidotus* Dr. Traquair distinguishes three new species, and is able to publish a good restored figure of *L. bernissartensis*. There are also a few specimens of a small *Notagogus*, which seems to exhibit scales more cycloidal than usual.

The numerous specimens of Pycnodonts appear to belong to a single new species of *Mesodon* (*M. bernissartensis*), of which Dr. Traquair adds an especially interesting restored figure. He considers that the supraoccipital bone enters extensively into the cranial roof, widely separating the parietals, as in the highest teleostean fishes.

A species of Eugnathid fish is referred to *Callopterus*, a genus hitherto found only in the Lithographic Stone of France and Germany; and there are two species of an Amioid, apparently of the genus *Amiopsis*, which is typically Cretaceous, but may also be represented in the Purbeck Beds.

The occurrence of *Pholidophorus* is doubtful, though probable; and there are several specimens of *Pleuropholis* and *Oligopleurus*, which are too imperfect for satisfactory specific determination. Dr. Traquair thinks that the *Oligopleurus* may be identical with *P. vectensis* from the English Wealden.

Leptolepid fishes are also abundant, including three new species of *Leptolepis* itself, and one new species of *Aethalion*, of which two excellent restored figures, internal and external views, are given. The *Aethalion* is a large fish, bearing much resemblance to the so-called *Leptolepis valdensis* from the Wealden of Southwater, Sussex.

In conclusion Dr. Traquair summarizes his results, but refrains from expressing an opinion on the question as to whether the Wealden formation should be referred to the Jurassic or to the Cretaceous epoch. He might have added to the cited literature Professor Seward's determination of the Jurassic rather than Cretaceous affinities of the Wealden Flora. A comparative table of the species from Bernissart and those from the English Wealden is given, and the total absence of Selachian fishes in the Bernissart collection is specially noted. As Dr. Traquair himself remarks, geologists may deduce their own conclusions from his results; and we should add that zoologists too

will find in the beautiful text-figure restorations much important material for generalizations. The actual fossils are represented on the plates by a series of photographs.

A. S. W.

II.—Geological and Topographical Maps: their Interpretation and Use. By Arthur R. Dwerryhouse, D.Sc., F.G.S., Lecturer in Geology in the Queen's University of Belfast. 8vo; pp. vii, 133, with 90 text-illustrations. London: Edward Arnold, 1911. Price 4*s*. 6*d*. net.

THIS work, intended as "A Handbook for the Geologist and Civil Engineer", is clear and concise, and illustrated (as the author tells us) mostly from actual districts in the British Isles, although the localities are only given in a few instances.

Commencing with a description of topographic maps, of the different scales adopted by the Ordnance Survey, and the methods of depicting the physical features, the author proceeds to give examples of the construction of sections from contoured maps, with a reminder that the miles represented along a road in a hilly country are longer than those on flat ground. The methods of constructing maps in lands where none exist are not dealt with, but the author gives instructions for rough surveys of small areas by means of the prismatic compass, in cases where more local topographic detail is wanted.

Turning to geological maps the various scales of those issued by the Geological Survey of the British Isles are duly noted, as well as the particular uses of the sheets issued with Drift and without Drift. Both editions, it may be remarked, are desirable in questions of water-supply and tunnelling, as Drift may be 200 feet or more in thickness. While the 6 inch maps are essential in practical inquiries, the 1 inch maps are rightly regarded as the most generally useful; and those which in recent years have been colour-printed have the advantage in most cases of a column of formations showing their relative thicknesses to scale, and of one or more longitudinal sections. The process of interpreting the structure and of drawing other sections is thereby greatly facilitated. For the latter purpose the 6 inch maps are desirable. In other cases the student may have to draw sections to ascertain the depth and thicknesses of strata from data given only on the geological map itself. Here knowledge is required not only of the sequence of the formations and of their thicknesses, but of unconformities. Some of these may be clearly marked; others, where for example Gault may rest on Oxford Clay, are only to be determined after close examination of the strata and their fossils. The many structural features in sedimentary and igneous rocks are explained and illustrated, including folds, faults, thrust-planes, flaws (fractures accompanied by horizontal movements displacing outcrops), and decussating folds (folded strata affected by later movements). The author rightly points out the need of paying regard to the general dip as opposed to local dips in the strata when dealing with the main geological features; and he further describes escarpments and dip-slopes, outliers and inliers, irregularities in thickness, lenticular beds, overlap, etc. When he remarks that

Gault is overlapped by Upper Greensand in the West of England, it should have been pointed out that the Gault in point of age is still represented in the basal sandy and loamy beds of the Upper Greensand.

From the descriptions and diagrams the student will soon grasp the relation of the rocks to the form of the ground and of outcrops to contours; and in a field-survey he will learn to complete his geological boundary-lines from the actual data observed along stream courses and scarps of rock, across tracts where the guides are mainly in the shape of the ground, and in the occasional outbreak of springs.

While the work, as implied in its title, does not deal with the variety of subjects of importance to the geological surveyor, such as are discussed in W. H. Penning's *Engineering Geology* (1880), in his *Text Book of Field Geology* (2nd Ed., 1879), and in Sir A. Geikie's *Outlines of Field Geology* (5th ed., 1900), it will be exceedingly useful for study and reference on the interpretation, the uses, and method of construction of geological maps and sections.

III.—The Mount McKinley Region, Alaska. By Alfred H. Brooks; with descriptions of the Igneous Rocks and of the Bonnifield and Kantishna Districts, by L. M. Prindle. Professional Paper 70, U.S. Geological Survey, 1911.

IN this quarto volume the authors have given a full account of what is known of the geology, physical features, and mineral wealth of the region, together with a history of previous explorations, and useful notes on the equipment necessary for the traveller. The climate, vegetation, and animal life are described, and it is pointed out that there is available a large amount of arable land, while the region also furnishes one of the best game-fields in Alaska.

The oldest rocks, which are probably pre-Ordovician, comprise schists, gneisses, quartzites, and subordinate limestones; then follow Ordovician (with graptolites), Silurian (?), Devonian (with corals, etc.), and Carboniferous (?). Triassic strata occur in Central Alaska, but not in the area now described. The Jurassic rocks contain andesitic and other lavas in the lower portions and some coal-seams (as yet undeveloped) in the higher strata. Cretaceous rocks are represented by limestone, black slates, and conglomerate. The Tertiary strata consist chiefly of freshwater beds belonging to the Kenai formation (Upper Eocene), and they contain important beds of bituminous and lignitic coals. There are also andesitic, basaltic, and rhyolitic lavas of post-Eocene and in part Pleistocene age, and extensive Pleistocene and Recent glacial and alluvial deposits.

The Igneous rocks are described by Mr. L. M. Prindle. The intrusive rocks are chiefly granites, granodiorites, and diorites. They occur in the Alaska range, where Mount McKinley rises to a height of about 20,300 feet, and in some other mountain tracts, including that of Talkeetna. There they appear to be mainly of late Jurassic age, but in other parts of Alaska some intrusions may be of Upper Carboniferous age, while others extend into Upper Cretaceous. There are no active or extinct volcanoes in the region.

Gold placer deposits are widely distributed in the Quaternary

gravels, and there is a separate topographic map to illustrate the Yentna mining district. The gold has been derived from auriferous quartz-veins in the Birch Creek schists and other of the older metamorphic rocks. The andesitic lavas of Jurassic age also contain a little gold.

Some account is given of the past and present glaciation of the region, and Mr. Brooks remarks that "A rough estimate indicates that less than 1 per cent of the area formerly covered by ice still remains buried under glaciers and perpetual snow. The present glaciers appear to be rapidly retreating and represent the lingering remnants of the larger Pleistocene ice-sheets". He further observes that "The subject of ground ice is worthy of mention. It appears that on the south side of the Alaska Range the ground thaws out to bed rock every season. North of the range ground ice is nearly everywhere present under 1 to 2 feet of soil and humous matter. This layer remains frozen throughout the year. Usually where the alluvial material is undrained the permanent frost extends to bed rock, in one place 318 feet of frost having been measured. Locally, however, where loose gravels are encountered, the material is not frozen".

Hot springs are noted on the borders of the Tanana River, a tributary of the Yukon, in the Baker Gold Placer District.

It only remains to add that the work is illustrated by eighteen excellent pictorial views and maps, geologic and topographic, and by thirty text-figures.

IV.—Cambridge County Geographies.

FOUR additional volumes have been received of the Cambridge County Geographies. They comprise East London, by Mr. G. F. Bosworth; Monmouthshire, by Mr. Herbert A. Evans; the Isle of Man, by the Rev. John Quine; and Carnarvonshire, by Professor J. E. Lloyd.

East London is taken to include the boroughs of Islington, Stoke Newington, and Hackney on the north, and those of Camberwell, Lewisham, and Woolwich on the south. The volume is an interesting one, containing accounts of the parks, commons, and open spaces, of the rivers past and present, water-supply, geology (in brief), rainfall, industries, and many other matters. The illustrations are good, and include a view in Epping Forest, a fair on the frozen Thames in 1814, bridges old and new, Canonbury Tower, Staple Inn, Holborn, London Wall, and many others. Although Boulder-clay is mentioned in the text it is not present in the area; on the other hand, Blackheath Beds should have been noted, with Woolwich and Thanet Beds, on the geological map. This work has the advantage of an index, which is not the case with the three other volumes now before us. In these space is taken up unnecessarily by a full instead of a local table of geological formations, while in the volumes on Monmouthshire and the Isle of Man there are nearly three pages (alike in both) dealing with an explanation of geology. Mr. J. G. Wood has contributed local geological notes, all too brief, on Monmouthshire. He remarks that the Severn Sea lies in a great "trough fault", but this is not

apparent from the geological survey map, although there is evidence of much faulting, folding, and unconformity. There are good views of the Usk and Sugar-loaf, of the Blorenge, and of the serpentine curves of the Wye. Agriculture, mines, and minerals are also dealt with. The alluvial levels bordering the Severn, locally known as "the Moors", are said to contain the deepest and richest soil in the county.

In the volume on the Isle of Man the geology is not satisfactory: it is remarked that "Underneath all rocks is the primeval granite, the foundation material of the earth's shell", and that the "very early granite" of Dhoon and Foxdale is covered by "Primary rocks, which may conveniently be termed Cambro-Silurian, i.e. of the same structure and formation as the Cambrian, the Ordovician, and the Silurian rocks of Wales". As the geological map at the end of the volume, based on that of the geological survey, gives these rocks as Manx Slates (Cambrian ?), the author might well have referred to the Survey memoir by Mr. Lamplugh to aid him in his geological descriptions, and he would then have learnt more about the "vast deposits of marl" beneath the surface in Kirk Andreas and Kirk Bride. In other respects the volume is full of interesting information, including remarks on place-names and surnames, antiquities, etc. The illustrations are effective, but those of Spanish Head, Calf Island, and Sulby Glen are not so clear as the picture of the Manx cat and many others. In the volume on Carnarvonshire the author acknowledges help from Mr. E. Greenly in the geological chapter, which is excellent though brief. Mines and quarries are separately dealt with, and there are views of the Penrhyn quarries. As remarked, there is a reduced demand for roofing-slate, as tiles are now more generally favoured by architects. Other views include the precipices of Carnedd Dafydd, Snowdon, Aberglaslyn Pass, Dolbadarn, and a group of black cattle. A concise history of the county may be mentioned among the many topics dealt with in this volume.

V.—Brief Notices.

1. Cotteswold Naturalists' Field Club.—In part ii of vol. xvii of the Proceedings of this Club (November, 1911), Mr. L. Richardson contributes a paper on "The Inferior Oolite and Contiguous Deposits of the Chipping-Norton District, Oxfordshire", describing in detail the succession of strata seen in many quarries in connexion with the 'Chipping Norton Limestone', so named by Hudleston in 1878. That limestone is newer than the *Clypeus* Grit of the Inferior Oolite, and represents the Lower Fuller's Earth; it is succeeded by a series of dark clays, together with marls and sandy limestones of estuarine character, to which the name 'Neæran Beds' has been given by Mr. E. A. Walford, while above comes the Great Oolite. In the Swerford area Mr. Richardson notes four subdivisions in the Chipping Norton Limestone, while elsewhere seventeen subdivisions are noted in the Neæran Beds. Local evidences of non-sequence between the Chipping Norton Limestone and beds above and below are indicated.

Mr. E. Talbot Paris describes and figures two new species of

Gervillia and one of *Perna* from the Neæran Beds. In further papers Mr. Paris contributes "Notes on some species of *Gervillia* from the Lower and Middle Jurassic Rocks of Gloucestershire", with text-illustrations and two plates, and a note on *Gervillia acuta* from the Scarborough Limestone. Mr. T. H. Withers gives a short note "On the occurrence of *Pollicipes* in the Inferior Oolite".

Mr. J. W. Gray deals with "The North and Mid Cotteswolds and the Vale of Moreton during the Glacial Epoch". In this article the author has discussed very fully the facts and opinions brought forward by various geologists. With regard to land ice he remarks that "There does not appear to have been any intrusion of these ice-sheets into the Cotteswold area, except, perhaps, the northern flanks and the Vale of Moreton"; and that "There are no signs of the passage of any of the great ice-sheets over the Cotteswold uplands". Some of the higher gravels are considered to have been "introduced by Tertiary streams that have been beheaded by the development of the Severn tributaries". The great accumulations of limestone-rubble on the Cotteswold slopes were probably due to "extensive snowfields liable to seasonal melting", as suggested by Witchell.

Although the Severn and Avon plain may have been subject to estuarine conditions during Pleistocene times, "there is no evidence that any of the gravels above a height of about 150 feet O.D. were laid down in an arm of the sea." Some of the marine shells, such as have been found at Cropthorne, may have been derived from Glacial beds in the Upper Severn valley. No evidences of Palæolithic Man have been found in the district described.

2. Mineral Resources of the Philippine Islands.—The Division of Geology and Mines, of the Bureau of Science, Manila, under the direction of the chief geologist, Dr. Warren D. Smith, has issued a report on the above subject (1911). The principal minerals are gold, silver, copper, manganese, and coal; and among other mineral products are building-stone, gravel and sand, lime and cement, brick and pottery clay. Occurrences of lead chromate, tin and zinc ores, platinum, and of beryl, spinel ruby, and garnet are recorded. The value of certain seepages of oil has yet to be proved. Gold occurs in placer deposits, and also in veins in igneous rocks (granite, gneiss, felsite, and decomposed andesitic rocks), in contact-zones with the sedimentary strata, and in fault-fissures. The sedimentary strata appear to be of Oligocene, Miocene, and later date. The granite and gneiss are regarded as probably pre-Tertiary or early Tertiary, the diorite-schist as probably pre-Tertiary. Some andesitic rocks are probably Miocene. The coal-bearing strata are grouped as Lower Miocene or Oligocene; there are four principal seams of variable quality, bituminous and gas-coal; and it is estimated that there are many million tons in the islands, although it is remarked that the inferior coals are found in some of the more accessible districts.

3. The Magdalen Islands.—Observations on these islands in the Gulf of St. Lawrence, by Dr. J. M. Clarke, have been published by the New York State Museum (Bulletin 149, Albany, 1911). They consist of "a chain of disjected and sea-wracked remnants of

continental land . . . fringed with sand spits and dunes and tied to one another by tremendous sand bars". They form, in fact, "a fearful menace to the sailor and his craft."

The rocks comprise hard grey or mottled schistose sandstones, with overlying purple-red sandstones, probably Permian; and at the base diabase in sheets accompanied by tuffs, and permeated by thin seams and sheets of gypsum, with also enormous gypsum beds intimately associated with the diabase. The lowest strata include, though they are but rarely seen, shales and limestones yielding goniatites and other fossils, of Carboniferous age. These are described by Dr. J. W. Beede, with a number of text-illustrations. Dr. Clarke remarks that in nearly every soil-section of the red rocks, there is a thin but persistent layer of pure white glistening sand, no doubt decoloured by organic acids. The islands have never been subjected to glacial action: they owe their preservation to slow elevation in later stages of their history.

The work is illustrated by a map and many views of rock scenery, including the Great and Little Bird Rocks, which afford nesting-places for gannets and other sea-fowl. There are also illustrations of sand-dunes and of the action of sand-etching on pebbles and boulders.

4. Professor A. C. Seward's *Links with the Past in the Plant World* (Camb. Manuals of Science and Literature, Camb. Press, 1*s*.) is a popular discussion of the relative antiquity of existing plants and their distribution in past times as compared with the present, especially as illustrated by the ferns, the *Sequoias*, *Araucarias*, and *Ginkgo*.

5. Devonian Fauna of Wisconsin.—An important illustrated monograph on the fossils of the Middle Devonian of Wisconsin, U.S., has recently been published by Dr. Herdman F. Cleland in the Bulletin of the Wisconsin Geological and Natural History Survey, No. xxi. Prefaced with a brief sketch of the stratigraphy and a short bibliography, pp. 27–161 deal with the fossils, which are illustrated upon fifty-three excellent plates. The Cephalopoda are of special interest.

6. Oolitic Unios.—Mr. Wilfred Jackson has been paying especial attention to the figured types of Captain Thomas Brown and has had the good fortune to discover several of them among the miscellaneous fossils of the Manchester Museum. Of especial interest are two shells believed to be the originals of *Alasmodon vetustus*, Brown, from the Upper Estuarine Beds of Gristhorpe, Yorkshire. Mr. Jackson figures and discusses these in the *Naturalist*, 1911, pp. 104 seqq.

7. "The Resources of Tennessee."—This is the title of a monthly pamphlet issued by the State Geological Survey of Tennessee for the purpose of calling the attention of builders and others to the products of their own country adapted to their special requirements. No. 2 (August, 1911) is before us and deals with the Camden Chert as an ideal road material, the Ferndale iron-ore deposit, and cement materials in Tennessee. Three thousand copies are printed, and an appeal is made to the local Press to aid the work the Survey is attempting by reprinting the matter thus circulated.

8. Paul Choffat.—The friends of Dr. Paul Choffat will find a list of his geological publications in the Comm. Serv. Géol. Portugal, viii, 1911. It is conveniently divided into subjects and occupies 30 pages.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

December 20, 1911.—Professor W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

The President, in announcing the decease of Sir Joseph Dalton Hooker, O.M., at the age of 94, drew attention to the long connexion of that illustrious man of science with the Society, of which he was elected a Fellow no less than sixty-five years ago, in 1846; and stated that the Council had passed a resolution of condolence and sympathy, which had been forwarded to Lady Hooker. (See Obituary, Geol. Mag., January, 1912, p. 47.)

The following communications were read:—

1. "The Glacial Sections at Sudbury (Suffolk)." By the Rev. Edwin Hill, M.A., F.G.S.

The sections round Sudbury were described in two Geological Survey Memoirs: since the date of publication of these much more has been disclosed. A list is given of the principal sections now existing, with references to the descriptions in the Survey Memoirs and notes of those that are there undescribed.

The paper gives an account of a series of sands and silts, which lie at about 200 O.D. on each side of the present Stour Valley. They seem to indicate shallow-water conditions at a level more than 100 feet above the present valley-floor.

On the silts lies Chalky Boulder-clay. The transition from silt to clay is continuous, and seems to show that, here, the transition from formation of silt to formation of Boulder-clay was a continuous transition. The undisturbed condition of the beds indicates that during this transition there was no action of thrust or drag.

At lower levels, from 180 O.D. down to 100 O.D., on the flanks of the valley lie coarse gravels and sands, with current-bedding, which point to torrential water-action. Among these occur displaced masses of previously formed Boulder-clay, some contorted—as if by slip down slopes. At Little Cornard brickworks there is associated with current-bedded gravels a clay, in which are embedded very large masses of remade chalk.

The deduction from these facts is that at Sudbury, Boulder-clay began to be formed where there was quiet water, which stood on both sides of the valley at a level of over 120 feet above the present floor; and that, after such clay had been formed, there came to be strong currents into or along the valley, at various lower levels.

These deductions agree with the probable course of events, if a submergence preceded the Chalky Boulder-clay and an emergence followed it.

The Secretary read the following remarks received from Professor T. G. Bonney:—

"Unfortunately an engagement on Wednesday evening, made before I knew that this paper would then be read, prevents me from being present. That

I very much regret, since, as the author has taken me over all the sections (as I believe) described in his paper—in most cases two or three times at least—I should have liked to have expressed the opinions which I have independently formed. These are in full agreement with those set forth in his paper, so far as I can gather from the abstract. In the Sudbury sections at about 200 feet above O.D., a quite normal 'Chalky Boulder-clay' is seen overlying well-stratified silts and sands, with occasional false-bedding. These present every appearance of having been deposited under water, which was moving very gently and steadily. Their stratification shows no disturbance as it approaches the base of the Boulder-clay, and the latter does not in any way scoop or dig into it; but we find, not seldom, signs of a real, though rapid, transition from the one to the other.

"But, from about 180 to 100 feet O.D., that is more or less on the flanks of the Stour Valley (which the Glemsford boring has shown to be pre-Glacial)—sand, gravel, and Boulder-clay (normal) show great disturbance and strange associations—masses of the last material occurring in the others, like large irregular erratics. Their mutual relations are not suggestive of a ploughing-up by the snout of a glacier (which, had it deposited the Boulder-clay, would by this time have retreated from the district), but a downslipping of the older materials and a mixture of them with coarser gravels of more local origin.

"I may add that, sometimes in the author's company, sometimes with others, I have seen this orderly succession of silt, sand (more or less gravelly), and Boulder-clay, in other parts of the Eastern Counties, and not in them only. Thus, while I am fully conscious of the difficulties presented by the hypothesis of the subaqueous deposition of Boulder-clay, that which regards it as the direct product of an ice-sheet seems to me to involve yet more serious difficulties, at any rate in our Eastern Counties."

2. "The Ordovician and Silurian Rocks of the Kilbride Peninsula (County Mayo)." By Charles Irving Gardiner, M.A., F.G.S., and Professor Sidney Hugh Reynolds, M.A., F.G.S.

The Kilbride Peninsula includes three principal groups of rocks. The northern and western part is, in the main, composed of igneous rocks, contemporaneous and intrusive, of Arenig age; the southern and eastern part principally consists of Silurian rocks, but these are in the south-eastern corner of the peninsula faulted against an area of gneiss. The Arenig rocks resemble the Mount Partry Beds of the Tourmakeady and Glensaul districts—in the fact that they include cherts and shaly beds with *Didymograptus extensus*, and in the presence of gritty tuffs and coarse breccias, the latter rocks showing a magnificent development. No coarse conglomerates, however, occur, and no limestone breccias or other representatives of the Shangort Beds of Tourmakeady and Glensaul, while Arenig sediments of all kinds are very scarce. The most interesting feature of the Arenig rocks is the great development of spilitic lavas, which are commonly associated with cherts and often show good pillow-structure. Their resemblance to the similar rock of the Girvan district is very close. An enormous mass of felsite with large quartz-phenocrysts, and often albite, as also pseudomorphs after rhombic pyroxene, occupies much of the northern part of the peninsula. There is no doubt that it, like the similar masses of Tourmakeady and Glensaul, is of Arenig date. The Silurian rocks consist principally of grits, sandstones, and calcareous flags, and dip with great regularity in directions varying from south to east. The calcareous flags (Finny School Beds) are highly fossiliferous, and have yielded over fifty species, principally of corals and brachiopods, which prove the beds to be of Llandovery age.

Ill-preserved specimens of *Monograptus vomerinus*, found in the highest Silurian strata exposed, show that these are of Wenlock age.

Probably in early post-Silurian times occurred the intrusions of keratophyre and labradorite-porphyrite which are met with at, or near, the base of the Silurian. Then followed a period of important earth-movement, connected in all probability with the Caledonian movements in other regions. The area was folded into a syncline, the axis of which ran roughly north-east and south-west; and, perhaps owing to the rigid mass of felsite in the northern part of the peninsula, the Silurian rocks in adjusting themselves became traversed by numerous cross-faults. At some latter period intrusions took place of numerous small dykes and sills of dolerite.

Dr. Henry Woodward, F.R.S., supplies an Appendix giving a description of a new species of *Caryocaris* (*C. kilbridensis*).

II.—Mineralogical Society.

Anniversary Meeting, *November* 14, 1911.—Professor W. J. Lewis, F.R.S., President, in the Chair.

R. H. Solly: Dufrenoysite, associated with seligmannite from the Binnental. In a small cavity, discovered in August, 1911, in the dolomite rock in the Lengenbach Quarry, were a few brilliant crystals of dufrenoysite, coated on their fractured surfaces with minute crystals of seligmannite. Measurements of two crystals of the former led to the discovery of twenty-six new forms. — H. G. Smith: A simple graphic method for determining extinction angles in sections of biaxial crystals. A means of drawing a crystal projected on any plane and finding the extinction directions was explained.—Dr. G. T. Prior: On the Meteoric Stone which recently fell in Egypt. A meteorite fell on June 29, 1911, near the village of Abdel Malek, about 44 km. E.S.E. of Alexandria. It exhibits a brilliant, varnish-like crust, and consists mainly of a coarse-grained crystalline aggregate, without chondrules, of a green pyroxene, and a brown ferriferous olivine, with only a little felspar and practically no nickeliferous iron. A quantitative analysis showed that the stone included a high percentage of lime, and that the green pyroxene, containing much lime as well as ferrous oxide and magnesia, constitutes about three-quarters of the stone by weight. A study of thin sections under the microscope showed that the pyroxene is generally twinned on 100, gives extinction angles as high as 35°, and exhibits 'herring-bone' structure owing to fine twinning on 001.—T. Crook and S. J. Johnstone: Strüverite from the Federated Malay States. A mineral of doubtful identity found in the course of tin-mining on the Sebantun River, Kuala Kangsar district, Perak, was proved to be strüverite; it closely resembles the mineral recently recorded by Hess and Wells from South Dakota, U.S.A.—A. Hutchinson: On the temperature at which gypsum becomes optically uniaxial. A small plate of gypsum, cut normal to the acute bisectrix, was placed in a glass-topped cell, through which a stream of water at a determinate temperature was passed, and the optic picture was studied under

a microscope. The plate became uniaxial at 95° C.—A. Hutchinson: On a total-reflection diagram. From this diagram the refractive index of a substance is graphically determined when given the angle of total reflection with respect to a known substance of higher refractive index. By taking the sine of the angle as co-ordinate the curves are straight lines.—T. Crook: The occurrence of Ankerite in Coal. The white crystalline layers often found as infillings of the vertical joints in British coal are ankerite. Dolomite was not found and calcite occurs sparingly as compared with ankerite in the specimens examined.

CORRESPONDENCE.

THE WEALDEN FISHES OF BERNISSART.

Sir,—I greatly regret that the names of new species described by me in my recently published work on the *Wealden Fishes of Bernissart* (Mém. du Musée roy. hist. nat. Belgique, May, 1911) have been antedated by three years.

The cause of this was that the plates, which contain the explanation of the figures as well as the figures themselves, were printed off in 1908, it being expected that the work would be published in the same year. Unfortunately my MS. was not ready in time, and publication was delayed until last year, and then, in going over the proofs, I ought to have corrected the dates in the letterpress, inserting a note of explanation of the matter. Here I committed the mistake of imagining that the date 1911 on the title-page cancelled the date 1908 in the text and on the plates, never thinking that the reader would thereby be led to suppose that these new specific names had already been published in a preliminary Note, which is not the case, and the proper date of publication of the names in question is May, 1911.

Ramsay H. Traquair.

Colinton, Midlothian.

HUMAN ART IN THE RED CRAG.

Sir,—In his recent communication[1] to the Royal Society Sir E. Ray Lankester gives an account of the discovery, *below* the Red Crag of Suffolk and the Coralline Crag, of human tools—flint implements. If there were tool-using men living while the basal deposits of the Red and Norwich Crag were being laid down, we should not find it hard to believe that there were men living while the mass of the Red Crag was deposited! Consequently the position taken up by the late Henry Stopes as early as 1881 is vindicated. In that year he read a short paper before the British Association, giving an account of a remarkable shell, engraved with a rude portrait of the human face, found in the stratified deposits of the Red Crag.[2] At that time

[1] See Geol. Mag., December, 1911, p. 576.

[2] H. Stopes, "Traces of Man in the Crag": Brit. Assoc. Rep., 1881, p. 700.